NUCLEAR ENGINEERING VOL. 4 NO. 41 OCTOBER, 1959

The First Export Reactor

LATINA carries the distinction of being the first power reactor to be exported. Letters of intent passed between Agip Nucleare and the Nuclear Power Plant Company in November, 1957, and the contract was finally signed at the end of August last year, when preliminary site work had already begun. The agreement between the two concerns goes much deeper than this single project and is designed to cater for a continuing constructional programme in Italy.

Outside the United Kingdom and the U.S., Italy has the most nuclear capacity planned of any country. Faced with the prospect of ever-increasing fuel imports and an annual increase in energy demand which is above the average the case for nuclear generation is clear. In addition to the Latina station itself, work should begin soon on the Garigliano station (General Electric's BWR) and the Selni-Westinghouse PWR in the north.

In its tie-up with Agip Nucleare the Nuclear Power Plant Company has established a pattern for international collaboration which is much more comprehensive in scope than was envisaged in the early days of power station development, particularly by British concerns. When the Magnox reactor appeared to be the only reactor capable of giving reasonable generation economics in industrialized countries, there was a strong tendency for British concerns to adopt an insular approach and to consider only turn-key contracts. Indeed some companies were not prepared to consider inquiries for reactors that did not automatically include the turbines and generators also. Those days are now passed, as time has proved that not only are there competitive reactor systems, but countries are not prepared to purchase nuclear power stations unless a significant proportion, at least of the conventional side, is handled by the buyer and unless the building programme allows a real gain in experience and knowledge by the indigenous scientists and engineers.

The NPPC-Agip agreement, however, goes further than this and looks for a progressive increase in stature of the foreign partner leading to genuine collaboration with contributions by both sides. At this stage of the arrangement no doubt interpretation of the agreement presents some problems as the experience of the British firm will be vastly greater than that of its associate, but, eventually, the Italian-British partnership should result, not merely in a strong commercial bond but also in material technological gain.

Even between equal partners there are always considerable problems in organizing joint research and development, where both sides genuinely benefit and too much time is not lost in committees and in travelling. There is always the danger that the division of responsibility reduces the efficiency of both and decreases the overall output. We've also yet to see how this joint development arrangement can be successfully married in with the new link-up between NPPC and A.E.I.-John Thompson. But, this principle of establishing co-operative bonds rather than agencies should do much to exploit the potential effort available; it is also the most effective method of "selling" reactor systems.

Latina is unique in that it is the first of the second designs to come from a British concern. It can be more truly regarded as a design evolution from Bradwell than, say, Hinkley Point which was able to take advantage of the first attempts but emanated from a different team.

The articles on the station published in this issue (pp. 329-342) illustrate the type of development that has characterized (and will still mark) the progress of the Magnox reactors. Basically the design is the same as Bradwell but a number of changes have been introduced which lead to a reduction in cost and an improvement in efficiency, although in some instances this evolution may look like a convolution; Bradwell was designed initially with no sleaving in the fuel channels and these were introduced as a result of the investigations into Wigner energy build up. More precise information allows any release to be made during part-load operation.

On the civil side, the influence of the Italian engineers can be seen in the use of the bentonite process and the construction of a diaphragm wall. Although these are not exclusively Italian concepts they nonetheless can be regarded as the result of mixing British and foreign approaches to give an optimum technique. It is a tribute to the original development design team that such fundamental items as fuel elements have not changed whereas in the more conventional side such as the boilers, significant gains have been made.

Latina is not the final design in the Calder series and whilst some may forecast early superseding of Magnox cladding the steady improvements in efficiency that are made make it clear that any new system will meet stern competition.

Implications of the Select Committee's Report

THE report of the Select Committee on Estimates (pp. 355-358) must have made satisfactory reading to those past and present members of the Authority who were concerned with the planning and organization of the Industrial Group. It is rare for a select committee to be so warm in its praises and to give such unqualified support not only to the technical drive of a concern, but also to its expenditure control. Certain, very definite recommendations are, however, made for the future, and these will almost certainly be accepted by the Authority and appropriate action taken.

The committee would be expected to applaud the cost consciousness shown by all grades of staff in the Industrial Group although at times, to the outsider at least, the preoccupation of senior staff with finance allocations has seemed to take undue precedence over the technical programme. There is always a danger that cost accounting can become a major charge on an organization, but more important is the wastage of technical effort that is implied. This is perhaps in line with the length of time required to prepare budgets, a matter which was criticized by the committee, but if the group has erred on the side of excessive control it is more likely to gain continuing Treasury support than if the reverse had been true.

AEA Relations with Industry

The strong recommendation is made that more use should be made of the industrial research and development effort now available. The evidence given to the committee by the Authority and the consortia would seem to indicate that their relationship is still far from ideal. On the one hand the consortia are demanding a closer liaison with the AEA at an earlier stage in the development of reactor systems and on the other the AEA is complaining of the quality and number of staff attached to the AGR project. Contributory factors in this failure to come to terms are the lack of candour shown by both sides, the jockeying for position that goes on in the groups and the control over industrial relations exercised by the London Office of the AEA. Publicly both sides have always been anxious to emphasize the happiness of the relationship while in the background there has been much chuntering. Suspicion as well as competition has prevented a co-ordinated approach of the groups whilst in its turn the AEA has not been loathe to exploit the situation in order to maintain its control and also encourage the price competition. In their individual attempts to improve relations, the consortia were faced with a London Office, without direct experience of the problems of industry and of the design teams, which could rarely act with the flexibility and awareness that only this experience can bring.

It is most important, however, that the AEA and the groups now come to terms and that industry be made privy to the thinking of the Authority at as early a stage in planning as is possible. The periodic holding of conventions comes some way towards this but is not nearly enough. There are also organizations outside the big five who require and should be made aware of Authority thinking and in addition to meetings and the greater use of attached staff the Authority must consider the publishing of its policies to a much wider audience and in much more definite terms than has been the practice heretofore. This will, of course, make the Authority more open to criticism and its mistakes will become more obvious, but a flourishing Atomic Energy Authority requires a flourishing industry to exploit its developments and the public are more willing to believe in an organization that occasionally makes mistakes and admits them, than in one which appears to claim infallibility. There is always someone who is anxious to topple the position of the demi-god.

On Grounds of Economy

In its recommendations that much greater use should be made of industrial development potential, it is important to emphasize that the committee is not supporting this on the basis that this will assist the industry's finances, but on the basis that this should mean an ultimate economic saving to the country. The select committee's view-point is not that of a vested interest, but of a public representation, interested in public expenditure. Recommendations therefore, from this body for more work to be put out, must carry more weight than from other sources.

It is also on the basis of ultimate economics that the recommendation is made that too hard a bargain should not be driven in the granting of licences and the imposition of royalties. This is not for the industry's benefit, but for the country's benefit that the policy is urged.

Reducing Fuel Element Prices

Great emphasis is placed in the report on the concentration of this country's effort into one narrow line of development, particularly to standardize such items as fuel production and fuel processing. The committee look for the steady reduction in manufacturing and processing costs and it is largely from this standpoint that the splitting of the Industrial Group into Production and Development and Engineering is approved. The increase in the responsibilities of the individual works managers is regarded as of great importance in order to give the maximum incentive to bring production costs down. These organizational changes will, however, be negated if the price of fuel elements continues to be controlled by the London Office and is based not so much on a manufacturing price and a genuine anticipated life, but on a bargaining principle aimed at making the maximum profit and gaining the most advantageous sales terms. The problem is, of course, not simple, as the lifetime is so dependent on the mode of operation of the reactor, but if the works managers are to take charge of production costs they must be convinced that the results of any improvements will be passed on to the customers and will result in a reduction of generating costs, otherwise the incentive largely disappears.

DIGEST...

Surveying Significant News

Further Integration of Groups

Although NPPC and A.E.I.-John Thompson have not yet concluded their proposed agreement for nuclear collaboration the industry is speculating on a further similar tie-up between two of the other three British consortia. Preliminary discussions have already taken place on ways and means of working together but a final decision is unlikely to be made until the Dungeness contract has been awarded. G.E.C. appears to be looking overseas for its major collaboration.

Date of Criticality of Fast Reactor Goes Back

The Select Committee's report emphasizes the delays which the redeployment of staff from Dounreay to the production establishments caused in the fast reactor programme. In time this may prove to have been an advantage in allowing the physics to catch up with the engineering and new ideas to develop. The present delays stem not from a shortage of staff, nor from any absence of a feeling of urgency, but from the extent of the engineering problems still to be solved. Amongst these is the dynamic behaviour of the liquid metal loops which were essentially designed with static stresses in mind. The probable date of criticality is now the end of the year.

Reactors for the Universities

The imminent approach to criticality of the Jason reactor, being built by the Hawker-Siddeley Nuclear Power Company, coincides nicely with the beginning of the new academic year. The following three terms should see the plans of a number of the Universities and NIRNS crystallized, as a result of which at least three reactors are likely to be agreed. Only Imperial College at present aims to build its own reactor; the Midlands Universities are more concerned with devolving the responsibility of operation on to another body, such as the AEA. The long-term reactor programme of NIRNS and the location of future sites will materially affect decisions.

Application of Licensing and Insurance Bill

Although the Licensing and Insurance Bill came into force in July, it will be some time before the Ministry of Power's Inspectorate can assume the necessary responsibility for granting licences. At present control is still exercised by the Health and Safety Branch, and by the Reactor Location Panel, but an intensive programme of training is projected and it is hoped that in about two years' time sufficient experience will have been built up for the new corps to handle all but the more abstruse problems.

Progress in Research into Graphite Behaviour

The regular re-evaluation of the known data on graphite behaviour with varying temperature, and at differing radiation levels, emphasizes the complexity of the problems associated with the use of this moderator. Fortunately, to date, the new results appear to fall within the earlier predicted range of values, and it is now known that the original forecast of Wigner energy build-up at low temperatures was pessimistic; there still remains, however, a wide field for research at higher temperatures not only into energy storage and dimensional changes but also into chemical compatibility. The graphite story must serve as a permanent warning against the making of too bold assumptions regarding the behaviour of new materials in a reactor core.

Fuel Element Failure in SRE

A serious fuel element failure occurred on July 26 in the Sodium Reactor Experiment, operated for the U.S.AEC at Santa Susana by Atomics International. During an examination of the plant a parted element was found and preliminary indications are that the damage could have been caused by restrictions in the coolant passages as a result of the inadvertent introduction of an organic material into the reactor, caused possibly by leaks in the primary coolant pumps. Fuel elements are stainless steel tubes, each approximately ¾ in. in diameter and 6 ft long, containing columns of 6-in. uranium metal slugs. The tubes are capped at both ends and suspended in the core of the reactor by means of hanger rods from plugs in the upper shield.

Heavy Plate Welding Problems in France

A Euratom team has been studying in France the problems of heavy plate production for reactor pressure vessels. A British team visited Chinon earlier this year to give assistance on the prevention of brittle fracture following the appearance of a crack in the 4-in.-thick pressure vessel of EDF1. This crack emanating from a weld in the lower section of the vessel propagated for a distance of 10 m; attempts are being made to repair it *in situ*.

World Power Conference Plans

The 1960 sectional meeting of the World Power Conference will be held in Madrid, June 5-9. Some 17 or 18 papers will be presented by British authors of which seven will be on nuclear topics; Sir Christopher Hinton will examine the "Economics of Nuclear Power in Britain." At the sixth WPC in Melbourne in 1962 (probably Oct. 20-31) with the central theme "The Changing Pattern of Power," discussions on the practical experience gained in operating nuclear stations will be a prominent feature.

Ship Propulsion Problems

One of the rumoured decisions made by the Galbraith Committee is that the choosing of a reactor system at this stage of development is impossible. Certainly, as more information becomes available, the difficulties of installing a reactor in a surface ship appear more intransigent. Recent experiments on the BWR, for example, indicate that vertical acceleration of the core may introduce instabilities which would be difficult to control. More exact information on graphite contraction is leading some experts to believe that graphite moderation in a ship is impracticable, although there are vigorous objectors to this philosophy. Some statement, however, by the Galbraith Committee is required, and some lead must be given to industry on the probable rate of development as soon as a new government is formed.

Swedish Call for Tenders

A call for tenders is expected from Sweden at the end of this year for a nuclear power station in the 100 to 150 MW range. The call is expected to go out to both American and British companies, and the chances of a gas-cooled reactor being accepted are at present high. Initially proposing to develop its own heavy water moderated reactors for producing both power and process steam, Sweden has found that the estimated economics of the system have steadily deteriorated as development has proceeded. She is now looking outside for complementary ideas. The principle of underground construction to minimize shielding and containment costs will probably be adopted.

Rutherford Laboratory to Become Independent of Harwell

In line with the illogicality of the location of the CTR project, the decision has now been taken for the Rutherford High Energy Laboratory to become independent of Harwell services, which will require it to set up its own organization. One of the deciding factors in the choice of the Harwell site was the economy that could be made in the use of the AERE engineering and service facilities. Now these are to be withdrawn, and the accounts of NIRNS will correspondingly suffer. The new system appears not only highly illogical, but both wasteful of man-power and money.

HIFAR Facilities Available For Hire

The Australian Atomic Energy Commission is finding itself with spare capacity in its 10 MW heavy water moderated DIDO-type test reactor, HIFAR. Discussions are being held with G.E.C./Simon-Carves and the AEA on the possibility of hiring out space which would allow the AAEC to recoup some of the cost of this reactor. Before it went critical in April, 1958, the Lucas Heights project was subject to a number of delays owing to the shortage of funds and it seems that operational effort and cost are proving excessive when related to the modest and very long-term programme at present in hand. The cost of installing loops is extremely high, and often disproportionate to the amount of information that results. So far from the main centres of atomic energy research, HIFAR could be in danger of becoming a costly luxury.

WHO Considers Training of Public Health Officers

In the fourth report of the Expert Committee on Provisional and Technical Education of Medical and Auxiliary Personnel, the World Health Organization stresses the importance of officers responsible for the health of the public being trained in the various aspects of radiation hazards. The committee recommends that training in nuclear energy be regarded as an essential part of the instruction of all public health personnel, and that educational institutions be encouraged to establish appropriate courses. Government backing for such a policy in individual countries is also called for. WHO is asked to prepare a handbook to serve as a reference manual for public health workers.

PROGRESS REPORT ON CONSTRUCTION

Work on the site of the Latina Power Station began during the summer of last year. The foundations of the reactor building are completed and those of the turbine house nearing completion. Conditions on the site are discussed in detail below.

By Ing. M. CAMPANINI,
(General Manager, Agip Nucleare.)

THE nuclear power station under construction by Agip Nucleare in collaboration with the NPPC, and with the technical assistance of the U.K.AEA, is sited in Foce Verde, near Latina, some 100 km from Rome.

Preliminary studies for a site led to the selection of an area to the south-west of Rome which could easily meet future demands for southern Italy. The existence of a heavy load centre around the city of Rome restricted site surveying to the zone between Rome and Naples—the Agro Pontino—which is the present load centre for central and southern Italy.

Ground and water surveys were made to find a site giving adequate foundations for the reactor building, and a cooling water supply for the main turbines of 20 m^3/sec.

Preliminary soil investigation by percussion drilling near Borgo Sabotino revealed that the ground could support the reactor building loads, and samples taken from the drillings gave details of ground classification and mechanical characteristics.

Further investigations nearer the shore revealed a layer of tufo at a depth of some 30 m, overlying a layer of fine silty sand and a bank of consolidated clay.

The State of the Ground

Detailed examination of an area of about 107 hectares, 9 km from Latina and 15 km from Anzio, showed that the underground strata were of almost uniform characteristics.

Final selection of this area as the site for the power station was based on the results of these examinations, on the availability of good and easy access from the national highway, and on the proximity of Naples and Anzio.

Final borings were completed in June 1958 and work was begun on site roads, drainage, etc. 4,000 m of approach roads have been repaired and resurfaced, and

Fig. 1.—The site. Foreground : Reactor pressure vessel fabrication area. Left centre : Excavations for the reactor building. Right centre : Excavations for the turbine house. (April 22, 1959.)

on the site itself 1,700 m of roads of an average width of 6 m have been constructed.

At the time of writing site offices for the Direzione Lavori and the site stores had already been completed.

To enable a suitable foundation system to be designed, borings were made to determine the nature of the underlying strata. These borings also allowed penetrometer tests to be carried out, and where these proved unreliable compressive strength tests were performed by six rigs capable of percussion, rotation or jetted borings. Each rig was equipped with interchangeable samplers capable of dealing with the various strata likely to be encountered.

These investigations showed the existence of the following strata:

(i) alternate layers of uncompacted sandy, silty, and clay materials of volcanic origin, to an average depth of 12 m,
(ii) tufo of average thickness of 4 m,
(iii) fine, silty, sand of an average thickness of 3 m, and
(iv) consolidated clay, with homogeneous characteristics, to an ascertained depth of 50 m.

The design of the reactor building foundations was based on these findings.

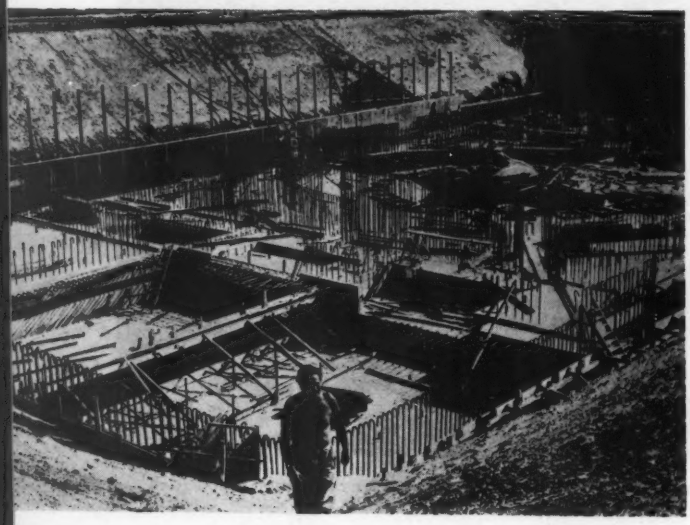
The Reactor Building

The main foundation for the reactor building consists of a reinforced concrete raft, 65 m × 31 m and 3.75 m thick, resting directly on a mass concrete bed supported in turn by the layer of tufo. This concrete bed was felt to be necessary due to the existence of fissures in the layer of tufo and the consequent need to avoid load concentration in particular areas of the raft. The rigidity of the raft ensures that no differential deflections will take place between the structural components of the reactor building. The casting of the bed and raft is now completed.

After loading the raft, any holes and fissures still existing in the sandy layer and in the tufo will be filled by injecting cement.

Before excavations for the main reactor building were commenced, a watertight diaphragm surround wall was constructed from ground level into the tufo, to a depth of 12 m to 14 m. This structure serves the double purpose of keeping water out of the excavations and as a retaining wall during the final stages of excavation. The method of construction is as follows:

Fig. 2.—The foundations for the reactor. (July 20, 1959.)



(i) a series of borings is made at 1.5 m centres down to the tufo, the bores being lined with steel tubing;
(ii) the bores are filled with bentonite mud, the steel liner is withdrawn, and the earth between the borings is removed by a grab of the same width as the steel liners;
(iii) stop-ends are introduced prior to the pouring of concrete;
(iv) reinforcements are placed in the excavation;
(v) concrete panels are cast by means of tremie, displacing the bentonite mud.

The succession of various panels constructed in this manner forms a continuous impermeable wall of reinforced concrete serving the following functions:

(i) resistance to vertical loads,
(ii) resistance to horizontal loads both longitudinal and transverse,
(iii) resistance to earth and water stresses,
(iv) protection for the excavation against ground water infiltration and slip.

A reinforced concrete beam cast on top of the diaphragm wall carries the Goliath crane track, the extension of the track beyond the diaphragm wall resting on piles.

The wall is now finished and the foundation excavations are completed from the +6.40 m level to the −6.50 m level; the bed and raft have been cast, and pouring of the main and secondary shield walls continues.

Concrete for the reactor building and foundations is being supplied by two batching plants each of 12 m^3/h capacity. Each plant consists of two 0.5 m^3 mixers, one 270 t capacity cement silo and one 100 m^3 capacity aggregate silo. Aggregates are handled by belt conveyors and bucket elevators, and cement by pumps. Each mixer is fitted with a 500 kg weight batcher and a water proportioner.

Concrete is placed in position by two 3-ton 30 m-jib travelling tower cranes. A smaller tower crane inside the biological shield will be used to handle shuttering.

The Turbine House

Work on building the turbine house (to be constructed in reinforced concrete) was commenced in parallel with that on the reactor building as preliminary investigations had proved this to be the most convenient arrangement. Excavation was actually started in March.

Consideration of the structural requirements for the different mechanical plant and, in particular, for the turbo-alternator groups, led to the design of a building having supporting columns positioned at 11 m centres.

The foundations of the turbo-alternator building and of the basement floor (in which the intake and discharge ducts for the condenser cooling water are incorporated) are completely independent from each other and are constructed by means of piling which reaches the supporting layer of the tufo. In addition, an adequate drain system will be designed to decrease the ground water upthrust.

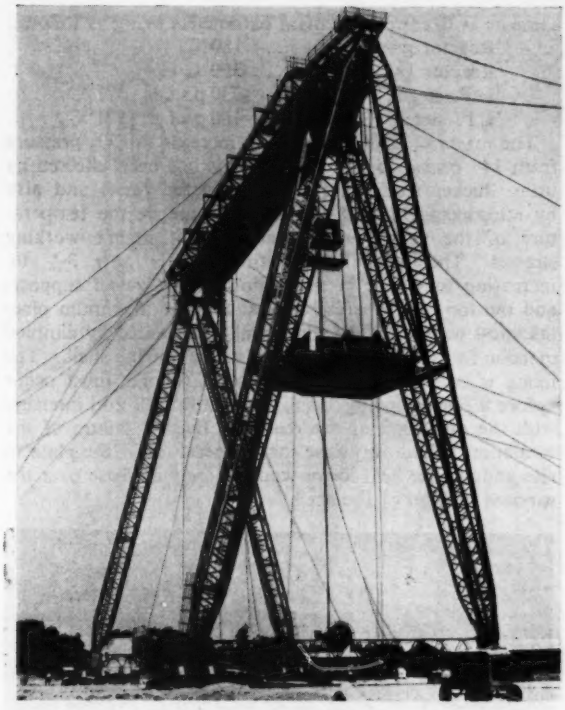
The foundation piles for the building are already completed and the driving of the auxiliary turbo-alternator foundation piles was begun at the end of May.

The building has an aluminium roof and is supported by main beams in reinforced concrete.

Due to the heavy nature of the loads, high tensile steel (the bars being deformed to give increased bond-strength) and high design stresses for the concrete were adopted.

Construction of the building will be carried out by erecting alternate bays, and each section of wall will be built at the same time as its respective portion of the floor, i.e., the construction of each bay will start from the plinths and proceed up to the roofing.

Fig. 3.—The Goliath crane, completed in early June last.



The Goliath Crane

One of the most important problems of the erection, lifting, and assembling of the reactor vessel courses, pre-assembled and welded on suitable plinths, and the lifting of the boilers, has been solved by the use of a 255 ton capacity Goliath crane, capable of being removed for use in the construction of other installations.

The driving of the piles for the crane track foundation beams is complete. So is the casting of some 170 m of both the north and the south beams. A length of 60 m out of a total of 300 m of track has been laid.

Details of the crane, which is of Italian design and construction, are:

main hook capacity, 265 tonne;
auxiliary hook capacity, 40 tonne;
effective span of the crane, 52 m;
effective height from the rail level to the lowest beam member, 50 m;
weight (crane without load), 680 tonne;
total power of electric motors, 390 kW.

The crane beam was assembled on the ground and raised into position by using the crane legs as gin poles. Construction was completed in early June.

The supporting beam is solid web. The winches are independent of the lifting crab and positioned on one of the vertical members.

COMPARISONS with BRADWELL

The Latina reactor including its components is essentially true to the Bradwell type but comparatively minor modifications in dimensions and operation facilitate a rise of output from 150 MW to 200 MW.

By R. D. VAUGHAN, B.Mech.E., A.M.I.Mech.E.
(Director and Chief Engineer, Nuclear Power Plant Co., Ltd.)
and Dott. Ing. G. CALABRIA
(Chief Engineer, Design, Agip Nucleare)

IN the design of Latina power station the prime objective was to obtain the highest possible output consistent with safe and reliable operation from a reactor unit of the same ruling dimensions and physical layout as the reactor units in Bradwell. By the time actual construction work began at Bradwell it was appreciated that with certain limited changes in design it would have been possible to increase the output from 150 MW per reactor to 200 MW. Another important advantage in using the same basic design was that all development work and experience on the Bradwell layout, fuel elements, and other key components would be directly applicable to Latina and the construction could therefore follow closely behind Bradwell without risk of delays which would have arisen in constructing an entirely new design overseas.

Initially it was not intended to modify any of the components which did not contribute directly to output. However, by the time negotiations for the construction of Latina were reaching finality, it was possible to incorporate several improvements in such features as, for example, standpipe closures, control rod arresting gear and control rod mechanisms. These changes have not made a major contribution to reduction in cost but will lead to sound operation and easier maintenance.

There were also some changes to meet the different requirements of the Italian site. These were primarily concerned with the design of the turbo-generator plant and the circulating water system, and with the layout of switch-gear and control rooms. It has not been necessary to modify the basic design or methods of construction of the reactor unit, and the major lifts will still be effected with a Goliath crane built in Italy specially for the purpose.

Modifications Resulting in Greater Output

The reactor vessel at Latina has a diameter of 66 ft, and all the coolant temperatures and steam conditions are the

same as at Bradwell, the main parameters being as follows:

Reactor gas inlet ..	180°C	
Reactor gas outlet ..	390°C	
H.P. steam	730 p.s.i.g.	371°C
L.P. steam	180 p.s.i.g.	371°C

The major change has been an increase in CO_2 pressure from 147 p.s.i.a. to 197 p.s.i.a. This has been effected by using thicker steel plate for the reactor vessel and also by introducing internal insulation to reduce the temperature of the vessel and thereby permit higher working stresses. The general plate thickness is now $3\frac{9}{16}$ in. increasing to $4\frac{1}{8}$ in. in the region of the vessel supports and the top cap, whereas at Bradwell the maximum plate thickness was 4 in. The vessel will be insulated by dimpled metallic foil secured to the inner surface of the shell. The fixing is such that several coincident failures must occur before a portion of the insulation can fall off and interfere with the operation of the reactor. Even a failure of the insulation would not cause the temperature of the plate to rise unduly; the heat losses would merely increase over the exposed portion of the shell.

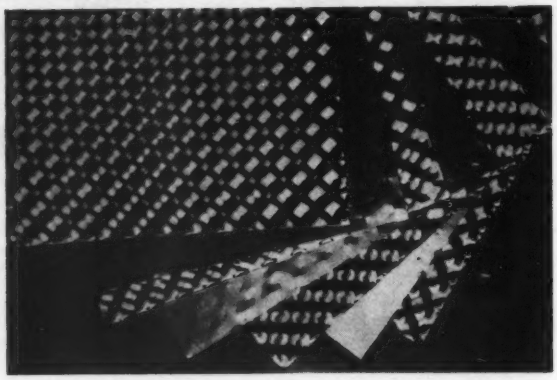


Fig. 1. — Dimpled metallic foil fitted to the inner surface of the Latina pressure vessel for heat insulation purposes.

The increase in gas pressure makes it possible to run the fuel elements at a higher rating, and these will now work at the limit currently accepted for a solid rod. The fuel can surface temperature will be 440°C and the centre uranium temperature during operation will not exceed the alpha/beta transition point. At the time the design was first put forward the core dimensions were just adequate to give the required heat output. However, the need for additional sector rods to control flux instability meant an increase in core diameter to avoid any loss in reactivity. The original active core diameter of 40 ft has now been increased to 41.7 ft, the height of the core remaining unchanged.

With 33% more heat output and no change in the operating gas temperatures the mass flow of gas has increased by the same amount. To carry the additional coolant flow economically the gas ducts have been increased in diameter from 5 ft to 5 ft 6 in., and so have the expansion bellows and gas valves.

It has been possible to reduce the overall dimensions of the six boiler vessels by closer packing of the finned heat transfer tubing and by employing finned tube in the superheaters instead of plain tube as at Bradwell. The boilers each now transfer 33% more heat with vessels 1 ft smaller in diameter.

The result of all these changes has been a net reduction in the ratio of blowing power to electrical output and an increase in net station efficiency from 28.2% to 28.4%.

Modifications to Improve Operation

When Bradwell was designed the calculation of the number and density of control rods could not be confirmed by experiment and therefore provision was made for more rods than will, in fact, be used. Since then measurements at Calder Hall and elsewhere have shown that a lower density of control rods will be satisfactory. Thus, in the Latina design, it was possible to provide for a simpler arrangement of standpipes in the vessel while retaining the principle of separate access for charging and control. The pattern is rectangular compared with the near hexagonal arrangement for Bradwell and the increased pitching has led to 30% fewer standpipes with their associated mechanisms and biological plug assemblies. The change also contributed indirectly to the raising of the working pressure of the vessel.

At the same time, opportunity was taken to standardize the standpipes and the method of sealing them. At Bradwell, access for charging is given through flap valves on the charging standpipes. For Latina, a self-locking seal assembly is used which can only be unlocked when the pressure across it is balanced, i.e. when the charge machine is coupled and ready for operation. This seal is also used on the control standpipes and makes it possible to replace control mechanisms and rods under load. This latter feature is desirable not so much for replacing an isolated mechanism which has become defective but rather to stagger the regular maintenance.

At Bradwell, the BSD pipes are brought through the control standpipe plug assembly and then through transfer ports to a primary selector valve on the pile cap. At Latina, this valve is incorporated in the standpipe assembly thus eliminating the transfer ports and a considerable amount of pipework; but the valve is still accessible because the assembly can be removed under load. Nearly twice as many sampling pipes have been brought up in each assembly although the selector valve remains the same in principle. An additional feature of the valve operation is that it is made to "home" frequently on a suspect channel without materially affecting the sampling of the other channels in the group.

The control rod mechanisms for Latina are similar in principle to those for Bradwell but are appreciably smaller. They have a higher gear ratio and therefore require less torque. Detailed improvements have been made to the chain suspension. The design of the control rod itself has also been simplified. The Bradwell rods incorporate a spring-loaded head box, which locates on the charge pan in the "in" position, and an arresting broach at the tip. The headbox has been eliminated which permits the rods to travel further into the core and so be more effective. It also simplifies recovery of a rod accidentally released. In the arresting device the broaching action has been replaced by one employing crushing because the latter is virtually unaffected by ageing.

On the pile cap there are several storage holes which have been grouped and access to them provided via turreted shielding plugs. This leads to a cleaner and more economic layout and dispenses with a number of heavy make-up pieces between the holes and the charge machine.

One of the major differences in design between Latina and Bradwell is the method to be adopted for overcoming the problem of energy storage in the graphite core. At Bradwell, in common with contemporary CEGB stations, the temperature of the graphite in the lower part of the core is being increased by placing removable insulating sleeves in the fuel channels. This is an expensive way of

ensuring that the bulk of the graphite does not store energy to a degree which could become critical during the working life of the reactor. At Latina, this solution would involve a further increase in core dimensions and also an increase in the initial charge of fuel, as well as additional running costs for the replacement of sleeves.

However, information on the problem is being continuously analysed by the U.K.AEA and it can now be shown that stored energy may be released safely by running the reactor at higher gas inlet temperatures when on reduced load. The procedure is known as irradiation annealing. To enable this to be done, it is necessary for the designer to ensure that the gas inlet ducts are capable of operating at temperatures up to 300°C and that during the operation the steam conditions will not alter materially. The Latina design meets these requirements and, if after 10 or 12 years of normal operation, irradiation annealing is shown to be necessary, it will be carried out during periods of low load.

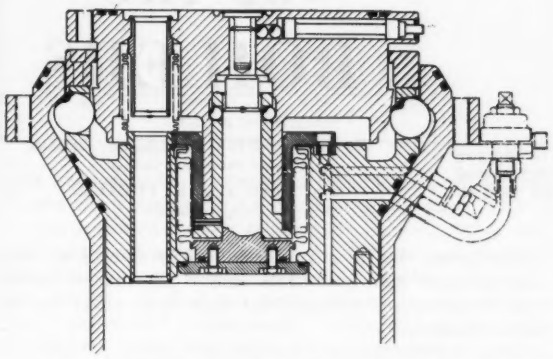


Fig. 2. — Latina-type Standpipe Seal Assembly. The plug body, which seals the standpipe (see Fig. 3), is retained by the large balls. These are expanded into the groove by the wedge action of the top section. Differential pressure across the plug raises the central piston, expands the inner balls and locks the two sections together, preventing accidental withdrawal.

Modifications Governed by Site Conditions

The different conditions of the site and of the electrical system to which the plant is to be connected, coupled with some differences between conventional plant design practice in Britain and in Italy, have led to certain variations in both general layout and equipment.

The blowers will be driven by electric motors on a variable frequency supply from auxiliary turbo-generators. For a single reactor it was obviously uneconomic to consider a full-duty turbo-generator in service with a second similar machine as stand-by. Therefore two 50%-capacity machines are being installed and the reactor will be able to operate at 80% full load when one is out of commission for maintenance.

The good climatic conditions at Latina, where temperatures below freezing point are unlikely, permit an outdoor arrangement of boilers, circulating water pumps, CO_2 storage plant, and pipework between the reactor and turbine hall. The site is not within a seismic area as defined by the Italian state regulations, but past records indicate the prudence of allowing for seismic stresses in the design of all structures essential to reactor safety. This has entailed minor changes in the reactor civil works and in the anchoring of boilers and charge machines. The pressure vessel structure has not been affected.

A separate building between the reactor and turbine hall houses the main control room and essential supply

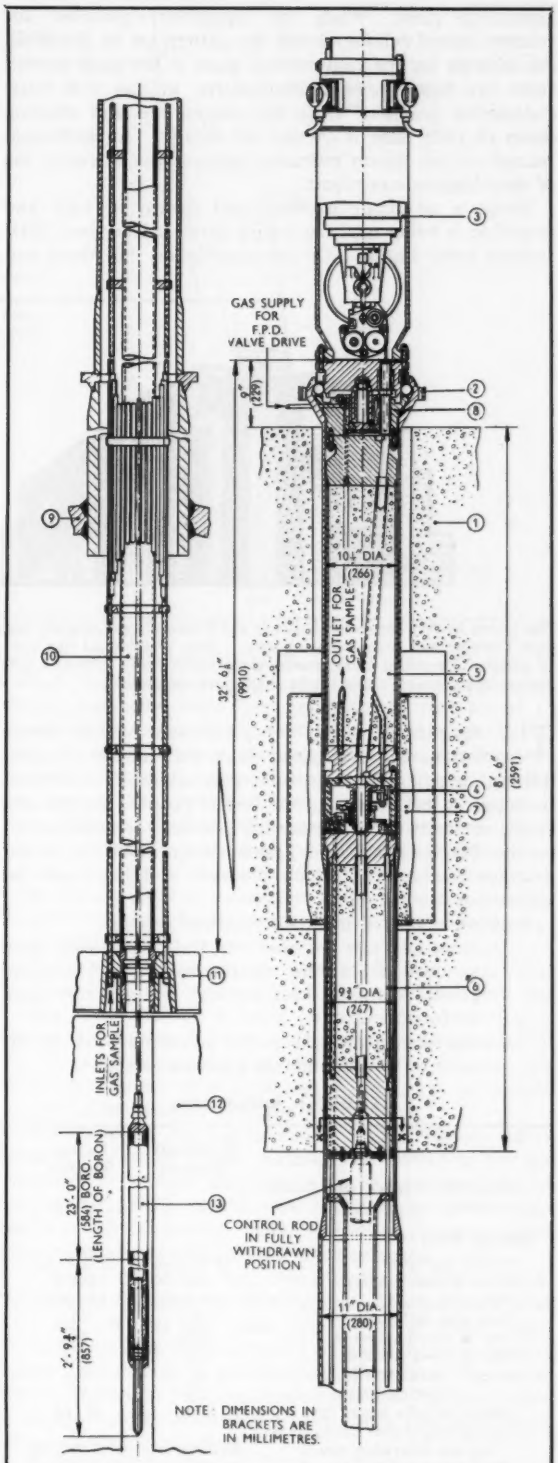


Fig. 3. — General arrangement of Latina-type Control Standpipe assembly. Key: 1 — Biological shield; 2 — Standpipe; 3 — Rod control head; 4 — F.P.D. Selector valve; 5 — Shield plug; 6 — F.P.D. tubes (31 per S/Pipe); 7 — Muff; 8 — Self-locking plug; 9 — Pressure vessel; 10 — Control rod guide tube; 11 — Charge pan; 12 — Moderator; 13 — Control rod.

generating plant. While the equipment provided for reactor control follows closely the pattern set by Bradwell, the controls for the conventional plant in the main control room are much more comprehensive, in line with latest continental practice. Only the starting up and shutting down of such plant is carried out locally. An additional feature of the station instrumentation is the extended use of data logging equipment.

There is no single national grid system in Italy and provision is being made to supply three independent EHV systems from Latina. On the assumption that these networks will be out of synchronism it has been necessary to install three main turbo-alternators, each of 70 MW gross output, whereas two 104 MW machines would otherwise have been satisfactory.

The lack of synchronism between supplies also affects the auxiliary electrical system and entails the use of dead busbars and the automatic transfer of incoming supplies to switchboards. All transformers have been increased in capacity to minimize voltage drops at the changeover, which means an increase in short-circuit level with 6.6 kV instead of 3.3 kV switchgear.

DETAILS of the BOILERS

By B. G. EDISS, A.M.I.Mech.E., A.R.T.C.S.
(*Nuclear Power Plant Co., Ltd.*)
and Dott. Ing. E. TORIELLI
(*Agip Nucleare*)

The Latina boilers represent basically the Bradwell type, slightly modified to improve heat transfer and manufacturing cost. *Inter alia* helical fins are provided instead of annular discs and tube elements of individually different lengths are used to occupy the available space in the shell more effectively.

THE designer of boilers for gas-cooled, nuclear power reactors having been given steam and coolant gas conditions, including the permissible pressure drop, is required to design a unit involving the lowest possible capital cost consistent with good engineering practice. A comparison of the Bradwell with the Latina design gives an insight into the methods by which progress is being made on equipment designs.

Improvements fall into two principal groups:

(i) those affecting the heat transfer matrix itself, such as changes in tube dimensions or arrangement, giving improved heat transfer and pressure drop performance;

(ii) engineering changes in the accommodation of the matrix in its containing pressure vessel.

TABLE I. Boiler Data

	Bradwell Station	Latina Station
Electrical output per boiler (MW)	25	33.33
Design Data:		
Boiler diameter	19 ft 0 in.	18 ft 4 in.
Area of shell (sq. ft)	284	264.2
Face area (sq. ft)	196.852	196.888
Face area utilization (%)	69.4	74.4
No. of thermal sleeves	1220	604
No. of rows of tubes	220	206
Pitch: horizontal (in.)	$4\frac{1}{2}$	$4\frac{1}{16}$
vertical (in.)	$2\frac{3}{4}$	$2\frac{1}{2}$
Depth of tube banks (ft)	50.4	39.188
Actual height over banks allowing for interbank space	69 ft $1\frac{13}{16}$ in.	57 ft $11\frac{3}{16}$ in.
Matrix volume (cu. ft)	9910	7716
Shell volume/MW (cu. ft)	786	459.2
Steam Conditions:	HP LP	HP LP
Drum pressure (p.s.i.a.)	790 223	788 221.5
Drum temperature (°C)	269 200	270 202
Superheater outlet temperature (°C)	373 373	373 373
Feedwater temperature (°C)	88	88

The Latina design incorporates improvements in both these groups; these constitute minor adjustments rather than revolutionary changes, but their total effect on the cost is marked.

Heat Transfer Matrix

Considering first the basic heat transfer and pressure drop performance of finned tubes, noticeable improvements are obtained by small alterations to the dimensions of the fin. All considerations of such improvements must take into account the cost associated with such dimensional changes, which, in their turn, are very much affected by the method of manufacture of the finned tube. Apart from small differences in fin dimensions, the difference between the tube for Latina compared with that for Bradwell is one of manufacture. The Bradwell tube fins being annular discs manufactured by cold forming, it is inherent in the process that corner radii are produced. The tube for Latina on the other hand is produced by continuously welding a flat strip into a helix along the axis of a bare tube by a resistance welding process. This tube, the fin of which has a rectangular profile, is manufactured by Tube Products Ltd. of Oldbury.

Table 2 shows the dimensions of both the Latina and Bradwell tubes and the performances are compared in Fig. 1. This shows the tube footage required to perform various thermal duties, plotted against the total power loss to the station and calculated by the methods of Carr *et al.*[1] It will be seen that the relatively small change of dimen-

TABLE 2. Tube Data

	Bradwell Station	Latina Station
Tube bore (in.)	1.6	1.646
Fin outside diameter (in.)	2.82	2.821
Fin root diameter (in.)	2.19	2.002
Fin thickness (in.)	0.063	0.057
Number of fins (per ft)	64	64

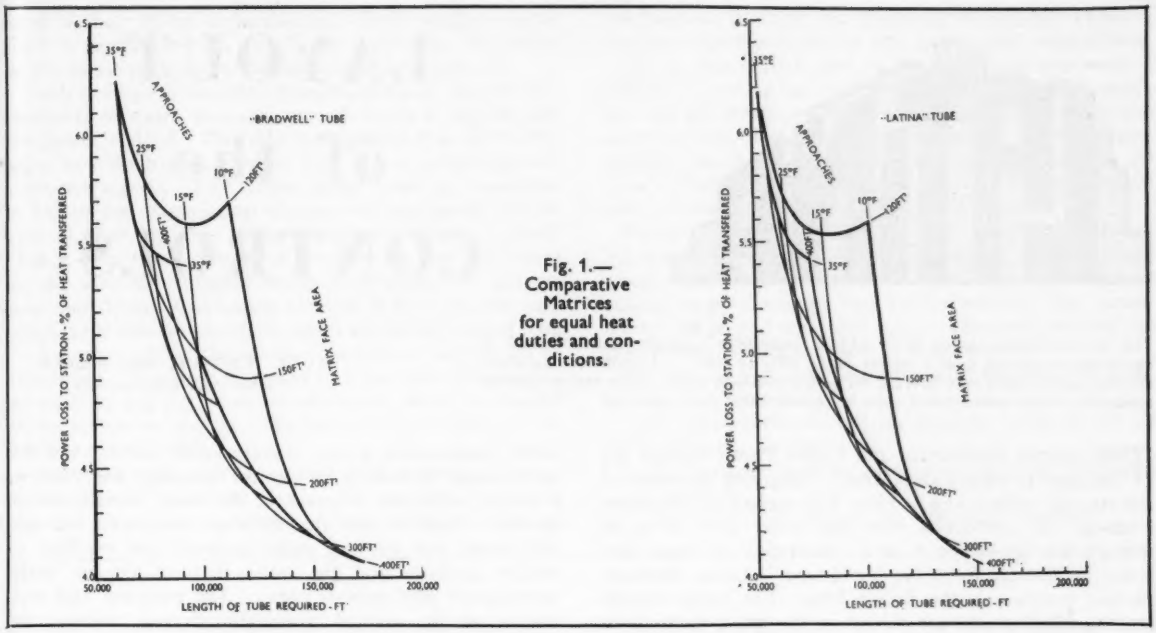


Fig. 1.— Comparative Matrices for equal heat duties and conditions.

sions has produced a substantial reduction in the footage of tube when assessed for a constant power loss. This is not accompanied by any substantial change in tube cost.

Investigations into the effect of the tube spacing and arrangement gave several interesting results. "In-line" arrangements showed no improvement in performance over "staggered" arrangements. Also, the performance of staggered banks was found to be insensitive to spacing changes in the directions of gas flow. Spacing changes in the direction at right angles to gas flow have a major effect on the matrix height, a minor effect on matrix face area, and almost no effect on the footage of tube used. Close spacings in this direction give the best results, with face areas only marginally increased and matrix height considerably reduced as compared with wider spacings.

Increase in gas pressure and permissible pressure drop reduce the matrix size still further; so, in the case of the Latina design, practical design problems in accommodating the heat transfer matrix are considerably reduced.

Engineering Design

In the original Bradwell design, bare tubes are used in the superheater sections for reasons connected with the possible reaction between carbon dioxide and the steel, but these have been found to be less important, and for Latina, finned tubes are used throughout.

The three-section superheater used at Bradwell, with its LP section placed between two HP sections, has been simplified. It was found that it was possible to locate the LP superheater with its relatively low heat load at the top of the boiler, whilst the gas temperature, in passing through this section, was not materially reduced, so that the same superheat temperature projected for Bradwell in the HP steam will also be obtained in the Latina boilers.

In the horizontal plane the use of tube elements of individually different lengths, allows the circular shape of the shell to be occupied more fully. The reduced vertical height of the matrix makes it possible to dispense with the special side opening for the insertion of tube elements, access through the gas inlet connection being adequate.

An investigation of the cost of the boilers manufactured for Bradwell indicated clearly that it was desirable to reduce the number of shell penetrations, as the thermal sleeves associated with these penetrations were found to be relatively costly. With penetrations on both sides of the boiler shell, the amount of steam piping and headers was considerably greater than it would have been, had the penetrations occurred down one side of the boiler shell only. The introduction of bifurcations, by means of which two tube elements are associated with a single shell penetration, overcomes this problem. At the same time, water velocities are kept to acceptable values, and considerable flexibility is given to the steam pipes, with the headers in a position which gives greatest ease of access.

The mechanical design was carried out bearing in mind the possibility of earthquakes. The district where the Latina Power Station is being erected is not considered a seismic area; however, since earthquakes have occurred in the surrounding areas, it was considered wise to check the structures against second-category earthquakes as defined by the Italian Seismic Building Regulations.

The layout of the Latina Power Station boilers differs from the Bradwell layout inasmuch as providing for the boilers to be situated outdoors, which has required special care with regard to the thermal lagging, and the arrangements of all the control valves and other elements which may be hand-operated in some circumstances.

It should be noted that, owing to the higher pressure, density and the great speed of the gas, the radiation level near and around the boiler shell will be rather high, especially at the voids between adjacent heat exchanger banks, where there is no shielding effect from the boiler tubes. Provision has been made for adding to these voids external shielding consisting of 4 in. thick cast iron panels where eventually required.

The boilers for Latina are manufactured in Italy by Nuovo Pignone, a Member Company of Agip Nucleare within the E.N.I. group, and the structure is designed to comply with the Italian regulations which are slightly more stringent than the United Kingdom regulations.

[1] Carr, F., Rounthwaite, C., and Young, P. A., *2nd Geneva Conference Report* No. A/CONF.15/P/2327. "Evaluation of Finned Tubes for Steam Generated in Gas-cooled Power Reactor Systems."

LAYOUT of the CONTROLS

The Latina station is to feed into a "star-type" supply network and is required to operate over a power range 20% to 100%. In addition, the main turbine and boilers will operate on a dual-pressure cycle. This makes control somewhat more complicated than in conventional stations.

By T. COXON, B.Sc., A.M.I.E.E.
(Nuclear Power Plant Co., Ltd.)

THE control facilities of the Latina Power Station are designed to ensure satisfactorily integrated operation of the reactor, boilers, and turbines with respect to the station loading. In connection with this latter point it is of interest that the station is on a "star-type" of supply network, as distinct from the "grid-type" station interconnection common in the British Isles. The Latina station loading requirements are subject to the direct fluctuations of the demands on the network.

The station is required to operate over a power range of 20% to 100% and to be able to accept transient variations of power and frequency of magnitudes shown in Table 1.

TABLE I.

Power steps	0% – 10%
Ramp power changes	0% – 5% per min
Random power changes	1%
Frequency changes	0.5 c/sec

In addition to this it is proposed that facilities be available to allow load reductions overnight as well as partial shutdowns, if required, over a period of about 36 hours (i.e., week-ends).

Individual Plant Control

The main turbine and boilers are designed to operate on a dual pressure cycle which makes control somewhat more complicated than in conventional stations. In normal operation (i.e., at fully automatic control), the HP sections of the turbines are on speed- or governor-control while the LP sections are on pressure-control. Facilities are provided, however for speed- or pressure-control of the HP and LP systems. These alternatives are required under certain operational conditions.

The mass flow of reactor coolant is controlled by the blower speed. In all, six blowers are supplied from two variable-speed auxiliary turbo-alternators working in parallel. This scheme has the advantage that one turbo-alternator alone can supply sufficient power to the blowers to ensure a mass flow of the order of 80% of the maximum. Reactor operation is such that over the power range the mass flow is only approximately proportional to power level since the reactor inlet temperature varies with power by some 40°C. The coolant outlet temperature is maintained sensibly constant by automatic adjustment of selected control rods.

Changes in reactor power are initiated by varying the coolant flow. An increase in flow cools the fuel slightly, releases reactivity and so causes power to increase. The outlet temperature is then slightly below normal and this is corrected by moving the control rods out. Fig. 1 shows a simple schematic diagram of the basic overall control system. It will be seen that there are essentially two control loops; one between steam demand and the flow of reactor coolant, and the other between reactor outlet temperature and control rods. The response and suitability of the overall automatic control ensures the following:—

(i) Desired rates of change of demanded turbine power are met with acceptable HP and LP steam pressure variations.

(ii) The reactor is maintained stable by overall rod control.

Automatic Rod Control

The function of the automatic rod control is twofold:—

(i) To maintain constant reactor channel outlet temperature, and

(ii) to maintain flux stability within the reactor.

The resultant action for effect (i) requires movement of a selected number of rods essentially together, while the action required for (ii) requires localized correction. Consequently, there are nine rods corresponding to one central group and eight sector groups each monitored individually and separately controlled from averaged temperatures derived from outlet channel thermocouples.

The signals from the thermocouples are fed into a controller together with a negative feed-back signal. The output signals from the controllers are fed to units supplying the servo-motors driving the auto-control rod generators which, in turn, supply power to the rod-drive motors.

The rates of rod movement available will be such as to provide suitable corrective action for bulk temperature control and individual sector control. In the event of any failure in the auto-rod control loop, it is arranged that the loop be opened; consequently, the rods will remain in the position applicable at the time of the fault. Alarms will operate indicating that the rods are in a position outside the limits of acceptable auto-rod movement and appropriate steps can be taken.

Station Power Control

For increase or decrease of load, the HP-turbine governor will operate in the normal manner and alter the steam quantity, reflected, in turn, by a pressure variation in the HP-lines. This variation about a given level will be detected by pressure transmitters operating from the inner and outer boiler HP-steam receivers and mounted locally

close to them in the turbine house. Each resultant signal feeds a recorder which, thus, gives continuous indication of the steam pressure in the relevant steam receivers.

Each pressure transmitter provides electrical signals proportional to steam pressure, one of which is selected for the power control. This selected signal is then fed to the input of a controller, together with certain stabilizing and reference signals. The output signal from the controller is fed to the manual/auto change-over equipment on the control desk. This latter equipment enables smooth change-over from manual to auto-control and vice versa of the auxiliary turbines which is necessary at start-up and shut down. Continuing forward in the loop, the next stage is the selector-switching which selects the control loop to the governors of the auxiliary turbine or turbines to be controlled. The governors raise or lower the turbine speed as required and the respective alternator output is supplied to the six blower motors. The control is operative over the power range 20-100%.

While, normally, power control is effected by following steam demand, provision is made for operation guided by the flux measuring equipment. This is of particular use during commissioning and testing. A signal is fed from a flux measuring channel into the power control loop via the manual/auto device. With this type of control in operation, the main turbines must run on pressure control or excess steam be absorbed by the dump condensers.

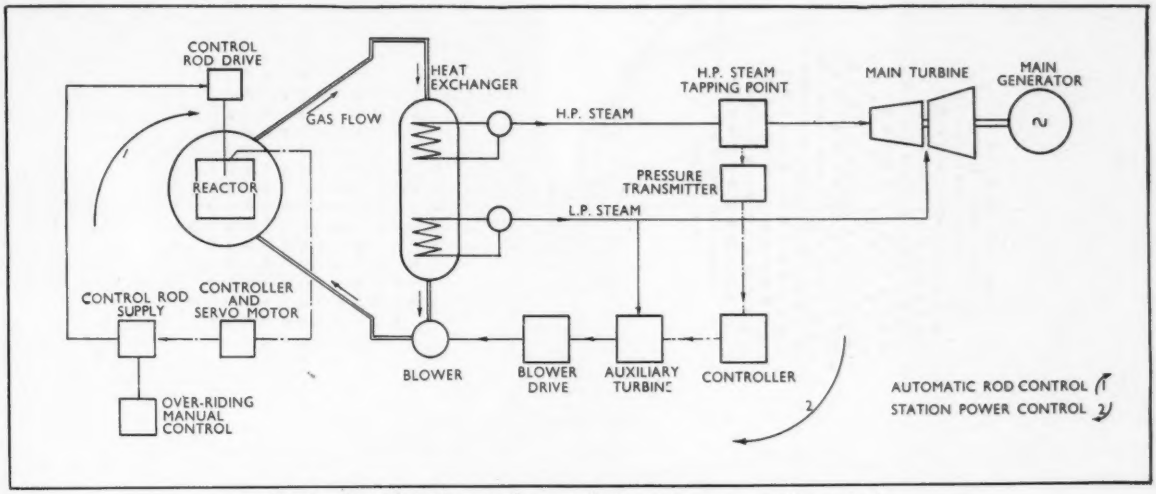


Fig. 1.—Simplified schematic for overall automatic reactor station control.

Operational Procedure

Start-up to 20% Power Level. After suitable positioning of the safety rods (fully out) and sector rods (about midway up channel) the bulk rods are withdrawn discreetly, a time switch preventing continual withdrawal for more than 20 minutes without supervision. The starting power is indicated by pulse counting and low level log channels. Up to a certain level, period meters operating from the low level log channels provide trip initiation. Normally, criticality will be reached in three to 10 hours depending upon the core temperature and the length of the shut-down period.

From the critical point, the bulk rods will be manually controlled to increase power at such a rate that the rise of fuel element temperature is of the order of 2°C/min. The pony motors will provide 20% mass flow throughout this start-up period. As the power increases, the boilers will begin to function and gradually develop LP steam at pressures corresponding to the gas-coolant temperature.

During this period, part of the LP steam generated is utilized in running up the auxiliary turbines to 20% speed, and the HP steam generated is used for running up and synchronizing one main turbo-alternator on governor-control. Excess steam is fed to the dump condenser. At some outlet channel temperature level below the normal level, automatic rod control may be selected.

Power Increase Beyond 20% Level. Increase in power beyond 20% of maximum is attained by higher blower speeds occasioned by manual or automatic station power control, with automatic rod control selected and operational; the second and third main turbo-generator sets are loaded when sufficient power is available.

For normal operation over the power range 20-100% the set up is as follows:—

(1) Main turbines: HP on governor control, LP on pressure control;
(2) Auxiliary turbines: preferably controlled via power control;
(3) Sector rod control: on automatic control;
(4) Bulk control rods: manual (infrequent adjustment unless load shedding, etc.).

Normal power reduction is achieved preferably by governor-control of the main turbines with full overall automatic-control operative. Depending upon the rate of power reduction and the final level required, some adjustment of the bulk rods may be necessary.

Operation of Control System During Trips

From a control point of view there are two types of trip, i.e., reactor trips and main machine trips.

When a reactor trip is initiated, the control rods fall into the core and the reactor snuts down within a few seconds. The automatic rod-control loop and the power-control loop are both tripped. With the loss of one or more main machines, the action is different. When the station is on full automatic control and one, two or three main turbo-alternators trip out, the control system is not locked out but immediately starts to reduce the reactor power. Stable conditions will be reached in a few minutes, but during this time some steam may have to be exhausted to atmosphere. This discharge could be reduced by use of the dump condenser. In the particular case of a three-machine trip, the power will be reduced to, and held at,

20%. To prevent excessive blow-off, the excess steam is passed to the dump condenser.

Safety Considerations

The first hazard which could cause concern is that associated with possible earthquake disturbances. Since these have occurred over Italy in general the Italian authorities have divided Italy into three zones of earthquake propensity, viz., 1st, 2nd, and 3rd. In the last category, normal buildings do not have to be designed for earthquake resistance. The Latina power station is actually in such a zone but the reactor buildings and nuclear plant have been designed to resist earthquakes relevant to the second category.

In the protection of the reactor against normal damage the prime aim has been to prevent excessive rise of fuel temperature above the design value. Should the ratio of the heat output to coolant flow exceed the design value, overheating of the fuel would occur. Whatever the cause, increase in heat output or loss of coolant, it is essential that the reactor be shut down. Great care has been taken with the design of the tripping circuits, the degree of reliability being much higher than in protective systems normally regarded as foolproof. The tripping circuits are designed to function on a " 1-out-of-2 " system. The safety circuits in general are designed to function on a " 2-out-of-3 " system.

The whole of the control system fails to safety. Neither the operation of the trip circuit nor the insertion of the control rods requires the guarantee of a power supply. The simplicity of the design of the control rod actuators ensures freedom of the control rods to fall into the core under gravity once the supply has been interrupted. These rods are divided into three main groups:—

(i) Bulk rods (manual control throughout);
(ii) 9-group auto-rods (manual or auto selection); and
(iii) safety rods.

The safety rods are never used during operation. They are held above the core and fall when the supply to their hoisting mechanism is interrupted. In an emergency, the electrical supply to all groups is interrupted and all the rods, the ends of which are always entered into holes in the core, fall under gravity to shut the reactor down. The diversity introduced by the various rod groups increases the improbability of failure to shut the reactor down.

Although the safety circuits can be regarded as extremely reliable, the consequences of their failure when the reactor has an overall positive temperature coefficient would be so serious that additional means of inserting negative reactivity into the core under major fault conditions have been provided.

Initiation is direct, occasioned by pressure and temperature elements not associated with the other trip circuits and not dependent on external supplies. They are contained within the coolant circuit and are, therefore, inaccessible to unauthorized persons. Should the coolant pressure change at an excessive rate, a number of control rods will be automatically released and so fall into the core whether the supply to their hoisting mechanisms be interrupted or not. Excessive rise of coolant temperature will release absorbing metal balls from a magazine into channels in the core. Either of these actions will insert at least $-1\%\ k$. Thus, there is an additional large inherent factor of safety. In the event of an earthquake disturbing the core alignment, the metal balls ensure a shut down.

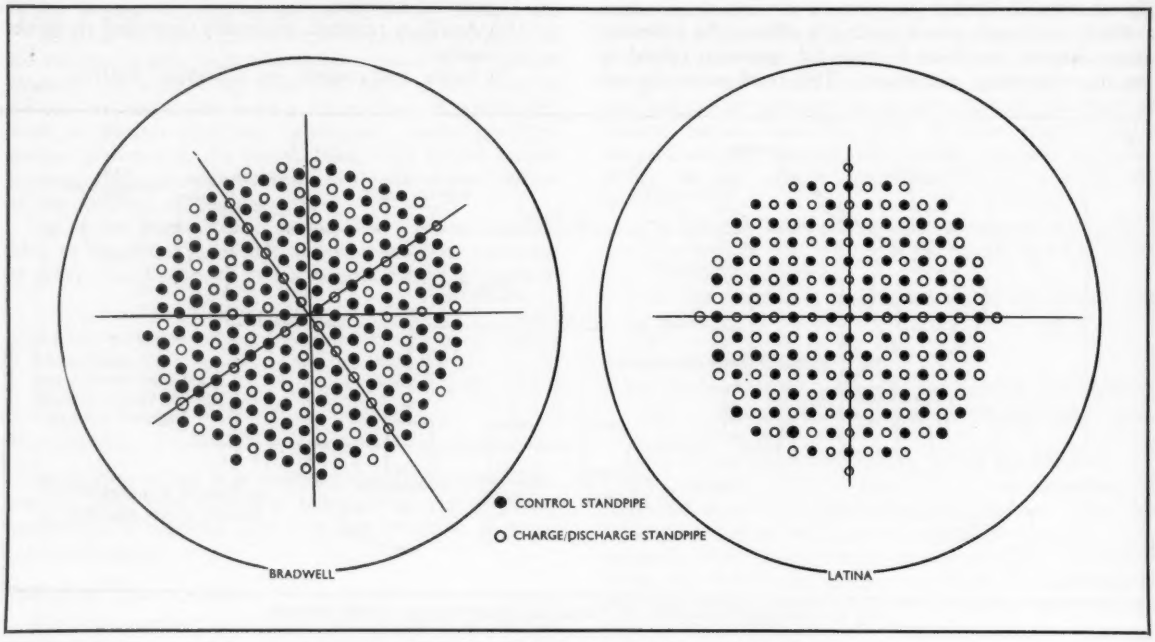


Fig. 2.—Comparison of Bradwell and Latina standpipe plan.

Accidental withdrawal of the control rods is the most likely cause of large increases in power without a corresponding increase in coolant flow. Accordingly, the maximum rates of withdrawal of the various groups of control rods and the interlocking between groups is such that mal-operation at start-up cannot produce excessive power surges. Likewise, the possible rate of rise of power at the design point is limited so that manual correction on receipt of warnings from a number of independent devices should be possible before reactor-trip circuits operate.

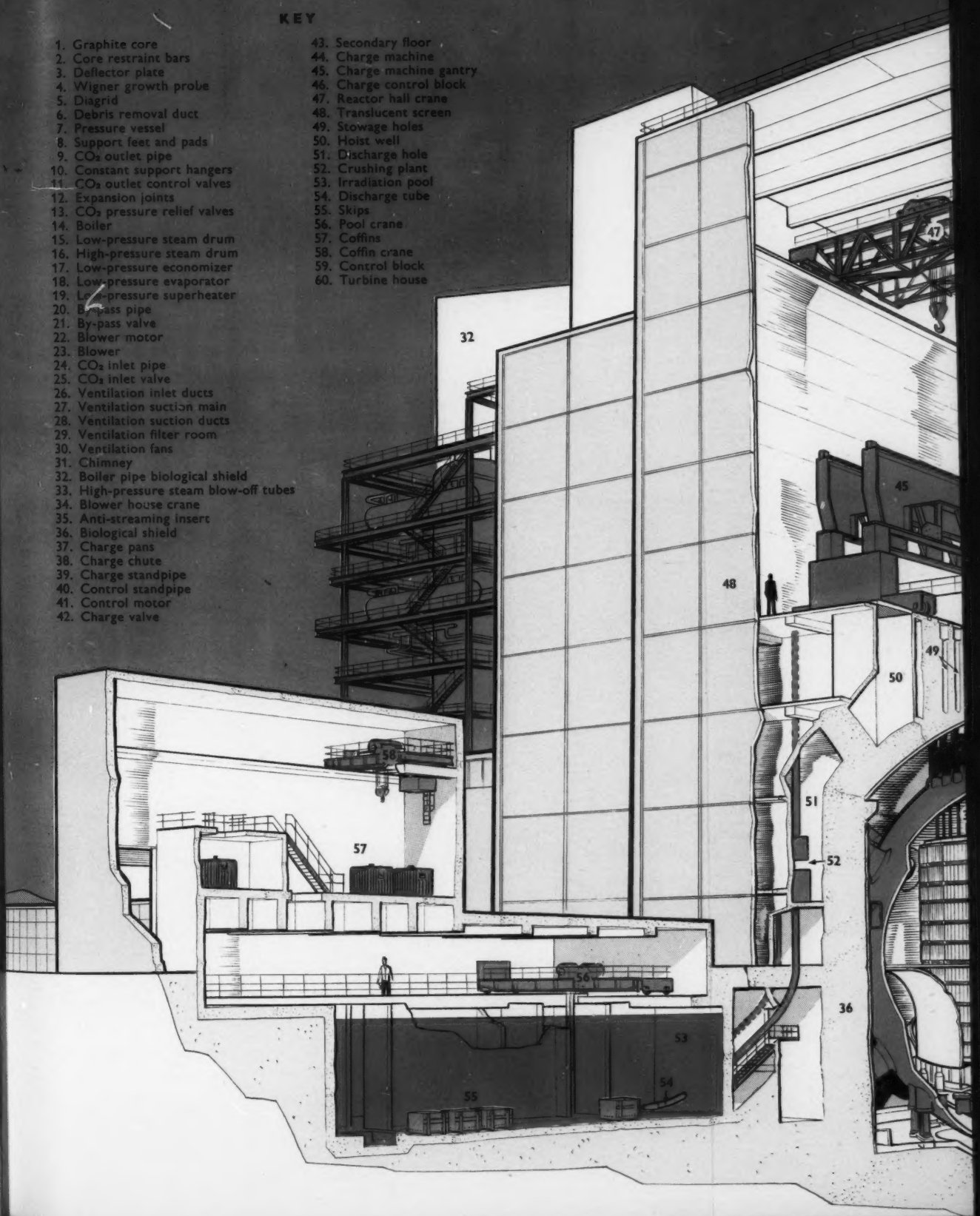
Reduction in coolant flow, due to failure of one or both

The World's Reactors

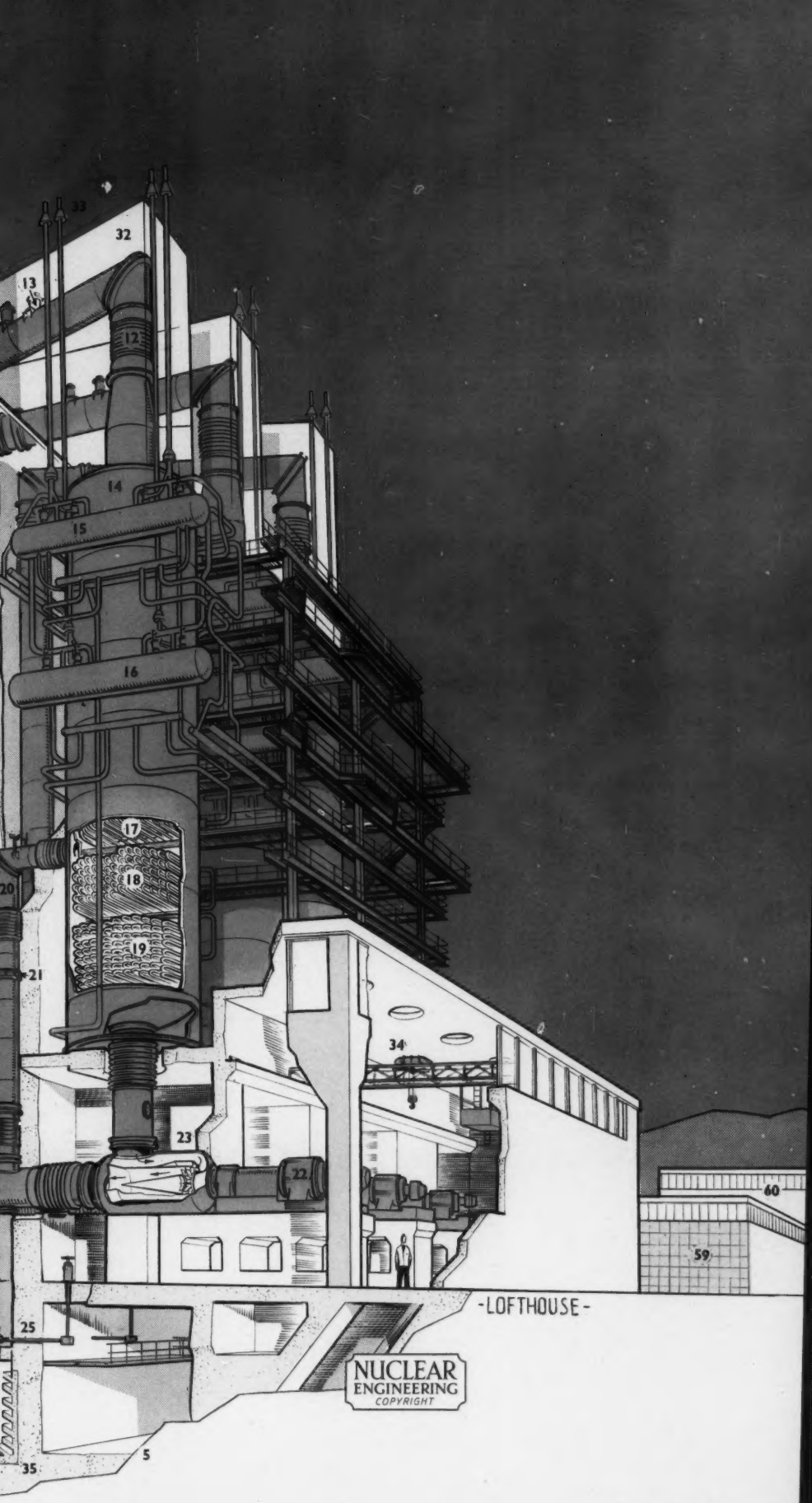
No. 22 LATINA

KEY

1. Graphite core
2. Core restraint bars
3. Deflector plate
4. Wigner growth probe
5. Diagrid
6. Debris removal duct
7. Pressure vessel
8. Support feet and pads
9. CO_2 outlet pipe
10. Constant support hangers
11. CO_2 outlet control valves
12. Expansion joints
13. CO_2 pressure relief valves
14. Boiler
15. Low-pressure steam drum
16. High-pressure steam drum
17. Low-pressure economizer
18. Low-pressure evaporator
19. Low-pressure superheater
20. By-pass pipe
21. By-pass valve
22. Blower motor
23. Blower
24. CO_2 inlet pipe
25. CO_2 inlet valve
26. Ventilation inlet ducts
27. Ventilation suction main
28. Ventilation suction ducts
29. Ventilation filter room
30. Ventilation fans
31. Chimney
32. Boiler pipe biological shield
33. High-pressure steam blow-off tubes
34. Blower house crane
35. Anti-streaming insert
36. Biological shield
37. Charge pans
38. Charge chute
39. Charge standpipe
40. Control standpipe
41. Control motor
42. Charge valve
43. Secondary floor
44. Charge machine
45. Charge machine gantry
46. Charge control block
47. Reactor hall crane
48. Translucent screen
49. Stowage holes
50. Hoist well
51. Discharge hole
52. Crushing plant
53. Irradiation pool
54. Discharge tube
55. Skips
56. Pool crane
57. Coffins
58. Coffin crane
59. Control block
60. Turbine house



1
2
3
4
7
8
9
10
11
12
13
20
21
24
25
26
27
28
29
30
31
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52



© TEMPLE PRESS LIMITED, 1959

The World's Reactors

No. 22 LATINA

OWNER:	Simea.
DESIGNER:	N.P.P.C./Agip Nucleare.
TYPE:	Thermal heterogeneous.
PURPOSE:	Power production.
CAPACITY:	200 MW(E) net. Heat rating: 705 MW. Number of reactors: one.
OPERATION:	1962.
FUEL:	Natural uranium metal rods. Dimensions: 29.3 mm dia. × 914.4 mm. Elements in vertical channels: 8 per channel. No. of fuel element channels: 2,853. Dia. of channels: 105 mm. Total wt. of material: 262.5 tonnes. Maximum temperature: 585°C.
CANNING:	Material: Magnox A.12. Wall thickness: 2 mm. Diameter over fins: 57.2 mm. Extended surface: helical fins.
MODERATOR:	Graphite: 'A' type. Active core size: 7.82 m high, 12.71 m dia. Overall size including reflector: 9.45 m × 14.25 m.
CORE:	Average temperature: 306°C. Lattice: regular square, 203 mm pitch. Thermal utilization factor, f: 0.57558. Resonance escape factor, p: 0.89295. Fast fission factor: 1.03341. Thermal fission factor: 2.00649. Multiplication factor, k: 1.06572.
PRESSURE VESSEL:	Mean dia.: 20.35 m. Thickness of plate: 90 mm. Total weight estimated: 1636 tonnes. Working pressure: 12.8 kg/cm².
COOLANT:	Carbon dioxide. Inlet temperature: 180°C. Outlet temperature: 390°C.
BLOWERS:	Number of circuits: 6. Number of blowers: 6.
CONTROL:	Number of channels: 100. Coarse: 91. Fine: 9. Rod design and construction: steel tube with ferro-boron insert. Rod length approximately: 8,350 mm. Suspension: chain. Shut-down speed: 1,270 mm/min. Minimum automatic speed: 12.7 mm/min.
REACTIVITY:	Total excess—unflattened region: 5%.
SHIELDING:	Concrete density: 140 lb/cu. ft. Biological sides: 2,565 mm minimum. 2,590 mm minimum top. Cooling: blown air.
HEAT EXCHANGERS:	Number per reactor: 6. Steam conditions: H.P. 52.4 atm. abs. × 373°C. L.P. 14.3 atm. abs. × 373°C.
MAIN TURBO ALTERNATORS:	Number of sets: 3. Rating: 70 MW. Speed: 3,000 r.p.m. Generator voltage: 11.8 kV. Alternator efficiency: 98%.
AUXILIARY TURBO-ALTERNATORS:	Number of sets: 2. Rating: 9.5 MW. Speed: 2,250 r.p.m.

Data sheets in this series already published in " Nuclear Engineering " are:

No. 1. BEPO (April, 1956)
No. 2. CP5 (May, 1956)
No. 3. NRX (June, 1956)
No. 4. DIMPLE (August, 1956)
No. 5. ZEUS (September, 1956)
No. 6. CALDER HALL (October and December, 1956)
No. 7. RUSSIAN 5 MW (November, 1956)
No. 8. DIDO (January, 1957)
No. 9. THE SOUTH OF SCOTLAND ELECTRICITY BOARD STATION (February, 1957)
No. 10. BERKELEY POWER STATION (March, 1957)
No. 11. BRADWELL POWER STATION (April, 1957)
No. 12. DOUNREAY FAST REACTOR (June, 1957)
No. 13. EBWR (July, 1957)
No. 14. RWE 1 (September, 1957)
No. 15. LIDO (November, 1957)
No. 16. PLUTO (April, 1958)
No. 17. MERLIN (May, 1958)
No. 18. G1 (June, 1958)
No. 19. HINKLEY POINT POWER STATION (July, 1958)
No. 20. NRU (February, 1959)
No. 21. HALDEN (March, 1959)

auxiliary turbines would cause a more rapid rise in fuel temperature than the rate of increase in reactivity on withdrawal of control rods. Hence, particular attention has been paid to maintenance of the coolant flow. The simultaneous loss of both auxiliary turbines is very unlikely, and there would not, under a reactor fault condition, be an immediate loss of the drive to the blowers. While it is not possible to maintain a sufficient flow of coolant to prevent overheating for all fault conditions, the arrangements are such that no overheating will occur while the pressure circuit remains intact and the reactor is tripped. Natural circulation is sufficient to maintain the fuel at less than design temperatures, but an auxiliary drive to the blowers providing 20% design mass flow is normally available so that even lower temperatures can be achieved. The inertia of the blower shafts has been substantially increased by the addition of flywheels. Their main purpose is to give time for emergency temperature-actuated devices to operate and so prevent too great a temperature excursion, should the normal tripping system fail to operate on loss of the main blower drive. This large inertia is also of value in the case of gross loss of coolant from the circuit. It is calculated that should there be loss of pressure such as would occur if a hole as large as a main gas duct were to appear, the overheating of the core, while severe, would not be disastrous even if the blowers were not available and cooling maintained only by natural circulation.

HANDLING of ACTIVE EFFLUENTS

The types of filter and treatment plant used to eliminate effluent are described briefly below. The basis of the estimates of activity in the discharged effluents is discussed and it is shown that the concentrations of activity are small compared with the international recommendations.

by L. N. SNELL, B.Sc., A. Inst. P.
and R. T. BRUNSKILL, B.A. (Cantab.)
(*Nuclear Power Plant Co., Ltd.*)

THE operations and processes in a nuclear power station involve inevitably the irradiation and subsequent activation of the fuel, moderator, canning, coolant, and general structural materials of the reactor. Table 1 itemizes the potential sources of activity in the Latina station and indicates the type of hazard associated with each source, i.e. whether the hazard is due to external radiation, ingested activity, or the chemical toxicity of the effluent.

Table I.

Potential Effluent	Type of Hazard
Shield-cooling air :—	
Argon-41*	external γ
Atmospheric dust	internal β, γ
Concrete dust	internal β, γ
Carbon dioxide :—	
Argon-41*	external γ
Carbon-14 from CO_2*	internal β
Graphite dust	internal β, γ
Plutonium and fission products	internal α, β, γ
CO/CO_2* mixture	toxic
Pond and wash water :—	
Plutonium and fission products	internal α, β, γ
Zinc-65	internal β, γ
Calcium-45	internal β, γ

Good engineering design and administration of the station ensure that escape of the activity is strictly limited and under constant control. In fact, discharge of most of the items listed above is effectively eliminated by the installation of filters, and water and gas treatment plant. For the remaining items (indicated by an asterisk in Table 1) the estimated concentration of activity in the discharge is so small compared with the recommendations of the ICRP (including the 1958 amendments[1]) that the capital cost or alternatively the running cost of plant necessary to eliminate the activity is not justified.

The toxic hazard of carbon dioxide/carbon monoxide is small compared with the radiation hazard and is, therefore, not discussed in the following analysis.

SHIELD-COOLING AIR

The neutron and gamma flux from the reactor core generates heat in the pressure vessel steel and in the concrete of the main biological shields. In order to limit temperatures and temperature differences in steel and concrete to safe values, such nuclear heat, together with the radiative heat between pressure vessel and main concrete shields, is removed from the system by the shield-cooling air.

Air is drawn from atmosphere into the main coolant duct vaults through sets of automatic roll filters which effectively remove all particulate matter of more than 10 microns diameter. The inlet air-stream, after filtration, is then split into a number of suitable paths to ensure adequate cooling of all regions of the pressure vessel/main biological shield void. Air from all circuits is finally collected in a large central ring main, extracted via duct work through further sets of automatic roll filters, and then exhausted at roof level to atmosphere by centrifugal fans.

The total quantity of air exhausted to atmosphere is 216,000 cu. ft/min at a temperature of 30°F above ambient.

Activities and Ground Radiation Levels

In transit through the reactor area, the gaseous and particulate constituents of the shield-cooling air are activated by neutron irradiation. The predominant

resultant gaseous activity is associated with argon-41 which is generated by thermal neutron absorption in the natural argon-40 of the air.

Thermal neutron fluxes are estimated for the relevant volumes of the reactor space and are found to vary between the limits 3×10^9 n/cm², sec and 8×10^7 n/cm², sec.

In conjunction with the thermal neutron absorption cross-section in argon-40 (0.53 barns), the mean argon content of the atmosphere (1.3% by weight) and a transit time of about 2 minutes, the total hourly discharge rate of argon-41 is estimated to be about 10 curies.

The air is also contaminated by traces of gaseous nitrogen-16 and carbon-14 together with active particulate matter formed by irradiation of incoming dust which penetrates the inlet filters and by abrasion of active surfaces in contact with the air. Since much of this particulate matter is removed in the outlet filters, the residual activity of the effluent gas on discharge at reactor roof level is due almost entirely to the presence of argon-41.

The subsequent behaviour of the active plume of air, after discharge, is dependent on the prevailing meteorological conditions (see Fig. 1) and on the velocity and temperature of the discharge[2, 3]. In a still atmosphere with a negative temperature gradient greater than the adiabatic lapse rate, the effluent gases rise continuously and the radiation level on the ground is negligibly small.

Under the alternative conditions of temperature inversion, the plume of active gas rises to a specific height, depending on the prevailing wind velocity and degree of inversion. The gases in the plume subsequently diffuse both vertically and horizontally in travelling downwind. At some point at ground level in the downwind direction, the radiation level due to the presence of the plume reaches a maximum value, the distance between this point and the reactor increasing with the degree of temperature inversion.

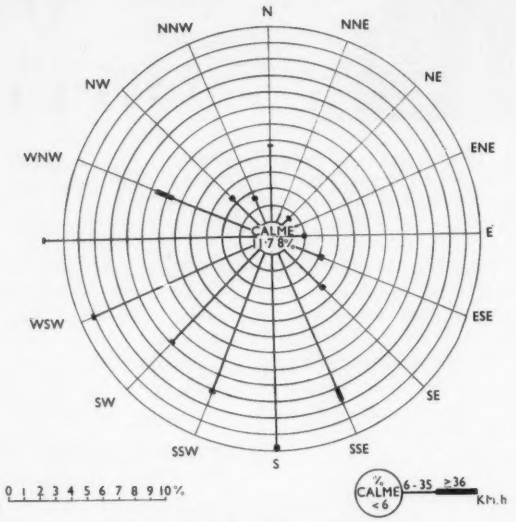


Fig. 1.—Wind spectrum — Latina.

The estimation of a time-mean radiation level at ground level for a point in the vicinity of the station requires a history of meteorological data for the region. On the basis of the available data the time-mean radiation level is estimated to be equal to that due to an "infinite cloud" concentration of argon of 8×10^{-10} μc/cm³. This figure is an overestimate because of the pessimistic assumptions made regarding the frequency of inversions, data on which are incomplete. A more realistic figure would be in the neighbourhood of 3×10^{-10} μc/cm³ which should be compared with the latest recommended ICRP maximum permissible concentration of argon-41, applicable to non-occupational minors, of 1.7×10^{-8} μc/cm³. The m.p.c. is thus about 20 times the maximum level quoted above and 60 times the probable level. The discharge of argon-41 does not, therefore, constitute a radiation hazard.

Monitoring Procedures

As a general safety measure, routine monitoring of the shield-cooling air will be undertaken using both portable and fixed instrumentation.

The portable monitoring equipment will be used by the health physics staff at the station for the measurement of ground and air concentrations. The gaseous and particulate activity, after the outlet filters and before discharge to atmosphere, is measured by the fixed monitoring equipment. A small fraction of the effluent gas is by-passed through a fine filter unit and, thence, through a gas chamber with a built-in end-window probe. Particulate activity is estimated by counting the filter for activity after allowing for the decay of natural radon breakdown products. Argon-41 activity is measured by β-counting under constant flow or constant volume conditions.

CARBON DIOXIDE

In passage round the coolant circuit, various gaseous and particulate constituents of the carbon dioxide become activated. The total circuit time is 25.8 sec, the coolant spending 1.13 sec in the reactor core in a mean thermal flux of 1.3×10^{13} n/cm², sec. The thermal neutron flux for other points in the circuit does not exceed 7×10^{10} n/cm², sec.

The main gaseous activity is due to argon-41 produced by thermal neutron absorption in argon-40, and nitrogen-16 produced by fast neutron-proton reaction in oxygen-16. Traces of volatile fission products (krypton, xenon, iodine, etc.) are present in the system due to irradiation of the uranium contamination on fuel cans burst fuel elements. In addition, small quantities of carbon-14 are present in gaseous form resulting from thermal neutron absorption in the coolant C^{13}, N^{14} and O^{17}. The particulate contamination of the coolant results from the oxidation of irradiated graphite and from fission products released as above. Little abrasion of the pressure vessel, ducting and heat exchangers is expected and in view of the relatively low irradiating fluxes in these regions the contribution to circulating activity from this source is small.

The total argon-41 activity is determined by the argon-40 content of the coolant, which is estimated at 1 p.p.m. in the supplied carbon dioxide. The level during operation may rise to 8-10 p.p.m. in the early life of the reactor due to outgassing of the graphite, but the level ultimately stabilizes at about 3 p.p.m., thereby giving rise to an equilibrium total coolant activity of about 40 curies of argon-41.

The specific activity of the coolant due to nitrogen-16 varies with location round the circuit between the limits 320 and 710 gammas/cm³, sec.

In passage round the circuit, about 2% of the total gas flow is by-passed through cyclones and silica gel driers which effectively remove particulate matter of more than 15 microns diameter, and all water vapour. On the basis of information made available at the time from the Calder Hall station, the rate of graphite oxidation has been

estimated for the Latina station (5 tons/y) and the equilibrium concentration of particulate activity calculated. The principal active isotopes in the coolant resulting from activation of impurities in graphite are cobalt, iron, sodium, calcium, manganese, dysprosium, and europium, the total associated activity in the whole circuit being about 1,000 milli-curies. Particulate activity resulting from the eroding of Magnox is, by comparison, small. Particulate fission product activity in the coolant results from the abrasion of irradiated uranium contamination on fuel elements and from the oxidation of the uranium surface in burst fuel elements. The total circulating activity is estimated to be a few milli-curies.

The burst slug detection equipment is used to detect increases in fission product concentration in the coolant, in the fuel channels and main ducts. In the case of a major burst, the fuel channel concerned is cleared of ruptured elements within 3-4 hours of its occurrence. In the case of a minor burst, the relevant channel is not cleared until the measurements of activity indicate that the burst is spreading. In either case, the increase in circulating fission product activity over normal background is only small and, for particulate activity, of limited duration.

Loss of Coolant

Coolant may be lost to atmosphere in the following three ways: as general leakage; as planned discharge during blowdown of the main pressure vessel and charge machine; under accident conditions with operation of the safety valves.

About 1% of the coolant may be lost each day by general leakage from the circuit. The rate of loss of activity from this source is less than 1 curie/day and the specific activity of individual constituents in the surrounding area will, in all cases, be less than 1/1,000 of the ICRP non-occupational maximum permissible level.

In the case of planned discharge or discharge through the safety valves, the coolant passes through ceramic or stainless-steel filters before final discharge to atmosphere, particulate matter of diameter greater than 2 micron being effectively removed. Some form of absorber will be included in the discharge routes as a means of removal of iodine and other volatile fission products. The associated activity in the ultimate discharge is due to argon-41 together with minute traces of fission product gases and fine particulate material of complex composition. It may be noted that because of its short half-life, nitrogen-16 decays to insignificant levels before discharge.

The ultimate ground contamination resulting from such a discharge is very small, of limited duration and, as a hazard to the surrounding population, can be ignored.

Monitoring Procedures

During normal operation the specific activity of argon-41 and particulate activity in the coolant is estimated by sampling the gas in the burst slug detection circuit. Argon-41 activity is measured using an end-window β-probe sealed into a gas container, and particulate activity by sampling a measured volume of gas through a fine asbestos filter which is subsequently counted for β-activity.

During blowdown of the charge machine and pressure vessel, provision is made for representative sampling of the discharge gas for particulate activity. A fraction of the main discharge flow is by-passed through one or other of two asbestos filters arranged in parallel. Under these conditions, the discharged coolant is continuously sampled and a rapid estimation of the particulate activity in the discharge obtained. The level of argon-41 activity in the discharge gases is not measured since this is entirely dependent on the argon-40 contamination of the coolant. Such variation as will occur is long-term, and can be readily detected by periodic sampling of the coolant circuit.

POND AND WASH WATER

Activated liquids are generated at the station in many ways, the major sources being the cooling pond, wash-down waters from the decontamination centre and from the decontamination of the charge machines, waters from coffin washdown and the active laundry. The activity is due predominantly to fission products and irradiated Magnox.

The station is so designed that all liquid activity is confined within the station perimeter, the ultimate discharge into the cooling water outfall being of negligible amount.

Pond Water

Normal fuel elements after discharge from the reactor are deposited in the cooling pond for a period of 100 days. In the case of burst elements, they are individually tinned before transport to the pond. Fission product activity is released into the pond from the irradiation of uranium as a contaminant on the outside of normal elements and on the outside of burst element tins.

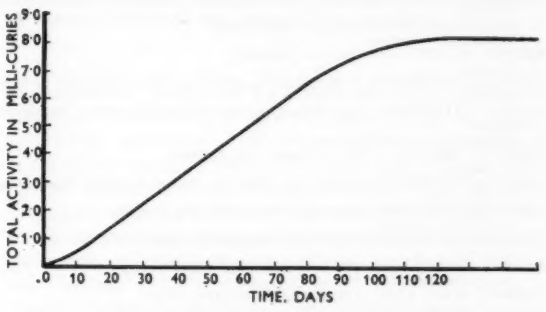


Fig. 2.—Growth of Zn-65 activity in pond.

Irradiated Magnox is released into the pond as a result of normal can corrosion. The specific activity of the pond water rises with time, the estimated variation in activity depending on the assumptions made as to the outside contamination of the fuel cans and to the rate of corrosion of Magnox in pond water. Assuming that fuel cans are contaminated with 0.1μg of uranium/ft length and that all such activated uranium is eventually deposited in the pond, the specific activity of the pond water due to fission products is 2×10^{-6} μc/cm^3 after one year's operation and 4×10^{-6} μc/cm^3 after 3 years. Assuming that the Magnox corrosion from one element is at a rate of 0.017 g/day, the equilibrium content of zinc-65 activity in the pond is 8 mc and the specific activity 1.2×10^{-5} μc/cm^3.

Smaller quantities of other active isotopes are released with Magnox corrosion, in particular, calcium-45 and iron-59, but the associated activity is only a small fraction of that due to zinc-65 (see Fig. 2). At the pH level of the pond water (=11), active zinc as sodium zincate is in solution together with the major part of the fission product release. The level of insoluble activity is kept low by continuous circulation of the pond water through

filter beds and coolers. When it is required to empty a section of the pond for maintenance purposes, the water is fed into an evaporator unit. The distillate from the latter is discharged into the outfall waters. Concentrated activity from the evaporator unit is sealed in metal containers and disposed of in the active waste disposal centre within the station confines. Heavy particulate matter which collects at the bottom of the pond is removed by dredging and filtration.

Filtration units used in this process and in the continuous cooling process are replaced at regular intervals or whenever the activity rises above some predetermined level. Units after removal are sealed in polythene sheet and disposed of in the active waste disposal centre.

Extra-Pond Waters

Wash waters from the decontamination centre, active laundry, etc., are fed along active drains to a series of primary holding tanks. The output from the holding tanks is fed directly into the evaporator units, the distillate from which is discharged into the cooling water outfall. The activity associated with these waters is similar in nature to that associated with pond waters but, since there is no accumulation of activity, the specific levels will be considerably smaller.

REFERENCES

1. "Recommendations of the International Commission on Radiological Protection" (September, 1958.) Pergamon Press, Ltd., London.
2. Bosanquet, Carey and Halton, *Proc. I. Mech. E.* 162 (1950), No. 3.
3. Sutton O. G., *A. J. Roy Met. Soc.*, 73 (1947), 257 & 426.

LATINA—Provisional List of Contractors

British

ACCLES AND POLLOCK LTD., Oldbury, Birmingham.
Tubing.
G. ANGUS AND CO. LTD., Newcastle.
Rings and oil seals.
APPLEBY FRODINGHAM STEEL CO. LTD., Scunthorpe, Lincs.
Plates, steelwork.
ATLAS STEEL FOUNDRY AND ENGINEERING CO. LTD., Armadale, West Lothian.
Steel castings.
WILLIAM BEARDMORE AND CO. LTD., Parkhead Steel Works, Glasgow.
Forgings.
T. BOLTON AND SONS LTD., Widnes, Lancs.
Commutator segments.
BROWN BAYLEY STEELS LTD., Sheffield.
Forgings.
CHARLES CHURCHILL AND CO. LTD., Scotswood Road, Newcastle on Tyne.
Screws.
CLYDE ALLOY STEEL CO. LTD., Craigneuk Works, Flemington, Motherwell, Lanarks.
Cylinder covers and bottoms.
CONSETT IRON CO. LTD., Consett, Co. Durham.
Steelwork.
CRAIG AND DERRICOT LTD., Royal Works, Sutton Coldfield, Birmingham.
Miniswitches.
DARLINGTON FORGE CO. LTD., Darlington, Co. Durham.
Steel bars, forgings.
DENNYSTOWN FORGE CO. LTD., Dumbarton, Scotland.
Forgings.
DORMAN LONG AND CO. LTD., Middlesbrough, Yorks.
Magnet yokes.
DOWTY SEALS LTD., Ash-church, Tewkesbury, Glos.
Seal washers.
EVA BROTHERS LTD., Crabtree Forge, Manchester.
Forgings.
EXPANDITE LTD., Chase Road, London, N.W.10.
Waterstop.
THOMAS FIRTH AND JOHN BROWN LTD., Sheffield.
Forgings.
FIRTH VICKERS STAINLESS STEEL LTD., Sheffield.
Forgings.
FLUIDRIVE ENGINEERING CO. LTD., Worton Road, Isleworth, Middx.
Clutches.
J. FOLKES AND CO. LTD., Stourbridge, Worcs.
Forgings.
FOUNDROMETERS LTD., Torbay Works, Hunslet Lane, Leeds.
Tachometers.
SAMUEL FOX AND CO. LTD., Stocksbridge, nr. Sheffield.
Steel billets.
GLADSTONES LTD., Portrack Lane, Stockton-on-Tees, Co. Durham.
Bolts.
G. A. HARVEY AND CO. LTD., 58 Victoria Street, London, S.W.1.
Ball floats and M.S. plate.
HEAD WRIGHTSON AND CO. LTD., Teesdale Iron Works, Thornaby-on-Tees.
Boilers.
N. HINGLEY AND SONS LTD., Netherton Iron Works, Dudley, Worcs.
Forgings.
HOFFMAN MFG. CO. LTD., New Street, Chelmsford, Essex.
Bearings.
J. HOLROYD AND CO. LTD., Milnrow, Rochdale, Lancs.
Gears.
ROBERT JENKINS AND CO. LTD., Rotherham, Yorks.
Dished ends and circulator casings.
RICHARD KLINGER LTD., Klingerit Works, Sidcup, Kent.
Cocks and gauges.
LANCASHIRE DYNAMO AND CRYPTO LTD., Trafford Park, Manchester.
Motors.
LIGHT ALLOYS LTD., 51 St. Leonards Road, London, N.W.10.
End rings.
MACNAYS LTD., Middlesbrough, Yorks.
Nuts.
MICANITE AND INSULATORS CO. LTD., Empire Works, Blackhorse Lane, London, E.17.
Rings and plates.
HENRY MOAT AND SONS, LTD., Brandling Park, Newcastle upon Tyne.
Aluminium sheets.
NEWTON VICTOR LTD., 132 Long Acre, London, W.C.2.
Radiographical equipment.
SAMUEL OSBORNE AND CO., Clyde Steel Works, Sheffield, 3.
Castings.
C. A. PARSONS AND CO. LTD., Heaton Works, Newcastle upon Tyne.
Turbines, blowers, bellows, etc.
PYE LTD., St. Andrews Road, Cambridge.
Television equipment.
PYROTENAX LTD., Hedgely Road, Hebburn-on-Tyne.
Reactor temperature measurement.
RAINE AND CO., Blackett Street, Newcastle on Tyne.
M.S. flats.
REDHEUGH IRON AND STEEL CO. LTD., Gateshead, Co. Durham.
Steel plates.
A. REYROLLE AND CO. LTD., Hebburn, Co. Durham.
Switchgear, graphite machining.
G. SALTER AND CO. LTD., West Bromwich, Staffs.
Springs.
SANKEY-SHELDON, 46 Cannon Street, London, E.C.4.
Unit strut inserts.
SILICA GEL LTD., Astonia House, Shaftesbury Avenue, London, W.1.
Silica gel.
SKINNINGROVE IRON CO. LTD., Saltburn, Yorks.
Steelwork.
STRACHAN AND HENSHAW, LTD., Steelhoist Works, St. Philips, Bristol.
Charge machine.
SOUTH DURHAM IRON AND STEEL CO., Stockton-on-Tees.
Magnet yokes.
STEWARTS AND LLOYDS LTD., Brook House, Upper Brook Street, London, W.1.
Steel tubing.
TALBOT STEAD TUBE CO. LTD., Green Lane, Walsall, Staffs.
Tubing.
TAYLOR, TAYLOR AND HOBSON LTD., Stoughton Street, Leicester.
Periscopes.
TEMCO LTD., Lydbrook, Glos.
Wire.
R. TRIST AND CO. LTD., Bath Road, Slough, Bucks.
Rubber rings.
TUBE PRODUCTS LTD., Popes Lane, Oldbury, B'ham.
Finned tubes.
U.K. AEA, Risley, Lancs.
Graphite supply, fuel elements.
UNIT SUPERHEATER AND PIPE CO. LTD., Unit Works, Swansea.
Standpipes.
VACU-BLAST LTD., Slough, Bucks.
Blast cleaning equipment.
VOKES LTD., Henley Park, Guildford, Surrey.
Filters.
WELDLESS STEEL TUBE CO. LTD., Wednesfield, nr. Wolverhampton, Staffs.
Tubing.
WHESSOE LTD., Darlington, Co. Durham.
Reactor pressure vessel, CO_2 ducting.

Continental

ANSALDO, Via Mura, Genova.
Auxiliary turbines.
ANSALDO SAN GIORGIO, 2 Piazza Carignano, Genova.
Auxiliary alternators.
CERETTI AND TANFANI, Milano.
Goliath crane.
C.G.E., 44 Via F. Casati, Milano.
Voltage regulators.
IMPRESA TORNO, GUISEPPE AND CO., 7 Via General Albrucci, Milano.
Main civil works.
K.S.B. EXPORT G.m.b.H., Frankenthal (Pfalz).
Boiler circulating pumps.
MAGRINI, SOCIETA PER AZIONI, 7 Via Luigi Magrini, Bergamo.
Site electrical equipment.
MARELLI-MILANO, MARELLI ERCOLE, 24 Via Borgonuovo, Milano.
Site transformers, blower pony motors.
NUOVO PIGNONE, 97 Via Panciatichi, Firenze.
Heat exchangers, boiler internal supports.
RICH SEIFERT AND CO., 5-11 Hermann-Behn Weg, Hamburg.
X-ray equipment.
S.A.I.P.E.M., Casella Postale 4179, Milano.
Plant erection for station.
S.I.P.A.C., Milano.
Site soil survey.
TOSI FRANCO S.P.A., 27 Corso Italiano, Legnano.
Main turbine condensers and feed heating.

The handling of plutonium necessitates special precautions. Containers are arranged so that the operator cannot accidentally create a critical condition.

Health Physics Aspects of Criticality

By H. J. DUNSTER,
(Chief Health Physicist, Health and Safety Branch, U.K.A.E.A.)

Once an assembly of nuclear fuel has reached the point of criticality it continues to release energy until something changes it to a sub-critical condition. This article reviews methods of detecting the release of radiation, the identification of exposed personnel and estimation of the dose.

IT is one of the boasts of the health physicist that radiation injuries are no longer a significant feature of the large-scale use of radioactive materials and of the development of nuclear power, but a succession of accidents over the past twelve months has cast some doubt on the validity of this claim and made it worth reviewing the problems of radiation protection which are introduced by such accidents.

Since the early summer of 1958 there have been three accidents involving radiation which have caught the public eye. In each case the accident has been a so-called criticality accident, involving the accidental arrangement of fissile material in such a quantity and form that a self-sustaining nuclear chain reaction became possible. In June, 1958, this occurred at a plant processing enriched uranium at Oak Ridge, in the United States, as a result of uranium solution leaking into a part of the plant which was being leak tested with water. In September, 1958, in Yugoslavia, an accident occurred on an assembly intended for studying the characteristics of a nuclear reactor by examining the sub-critical behaviour of the assembly. The accident caused the assembly to go critical[1]. Finally, a supposedly safe operation with plutonium at Los Alamos, in the United States, accidentally went critical in the last days of 1958. These criticality accidents all caused radiation injuries to several people and those in Yugoslavia and at Los Alamos caused one death each.

The methods of prevention of such accidents have already been discussed[2] in *Nuclear Engineering* by Gillieson. This article is concerned with the health physics problems which they pose.

Form of a Criticality Accident

It is difficult to generalize about the causes of criticality accidents because their dangers are so well appreciated that all the foreseeable causes are eliminated. No single error or mechanical failure will be a sufficient cause and in some cases not even three or four coincident failures or mistakes will cause criticality. However, once an assembly has reached the point of criticality it will continue to release energy until something changes it back to a sub-critical condition. In some cases, when the accident takes place in an assembly designed to approach criticality, there will be a series of shut-down devices and one of these will halt the reaction. In a chemical plant, however, it is not feasible to instal such devices everywhere where an accident is possible and the reaction may continue for some time, or it may become intermittent. Plans for dealing with a criticality accident must, therefore, take into account the possibility that the energy release will take place over a period of minutes or even hours.

The total energy released will depend on the speed at which the critical condition is approached, on the extent to which this condition is surpassed, and on the mechanism of shut-down. In physical terms the energy release is unlikely to be large, and an explosion, even a small one, is most improbable. Nevertheless, the radiation doses may be considerable, as the following example shows. A typical criticality accident might involve the fission of 10^{17} nuclei, causing a total energy release of 770 kilogramme calories. This would bring less than 10 litres of water to the boil, or vaporize less than 1.5 litres of water already at boiling point. The radiation dose would depend on the absorption of radiation in the assembly, but would amount to some hundreds of rads at a distance of 10 ft. Such a dose would certainly cause injuries and might cause death.

In the accident at Oak Ridge, described in detail in an unclassified report[3], the uranium solution leaked into tanks which were leak-tested with water. The mixture was then run into a 55-gallon drum, the high concentration solution entering first. The initial power surge was probably of the

order of 10^{17} fissions and was checked by the formation of gases caused by the radiation decomposition of the solution. This was rapidly followed by similar bursts, decreasing in intensity, until the solution reached boiling point and the formation of steam reduced the intensity still more. Finally, the reaction was stopped by the continued addition of water which lowered the concentration of uranium to a safe value. The total time involved was 20 minutes and the total number of fissions was just over 10^{18}.

Health Physics Problems

The health physicist has three basic aims in the event of a criticality accident. The first is to detect and locate the centre fast enough to evacuate the surrounding area in a matter of seconds. The second is to identify any one who has received a serious dose of radiation so that they can receive immediate medical care, and the third is to obtain an early estimate of the radiation exposures to guide the medical treatment. There will also be other problems, similar to those resulting from any serious radiological accident, for example, contamination of air and surfaces, and high radiation levels, but, in general, these problems will be subsidiary to those associated with the three basic aims.

Detection of the Accident

The importance of immediate detection of the accident will depend on whether the assembly is unshielded and has operators close to it, or is part of heavily shielded plant, far from the operators. Even where shielding is provided, it is not likely to give complete protection against a serious criticality accident, and early detection, while less important, is still necessary. In many cases the operator will be aware from his normal instrumentation that an accident has occurred. In others he may notice such things as a dull thud, a blue glow, or a smell of ozone, and these, possibly coupled with the recognition of an error just made, may enable him to recognize the accident.

At best these methods give only local warning and they are not sufficiently reliable to depend on. It is becoming usual, therefore, to instal radiation detection equipment which will give immediate warning of a criticality accident. The technical problems are often severe because the equipment has to detect the radiation from an accident in a location which often cannot be identified in advance and which may be anywhere in a very large area of plant. A grid of detectors is then necessary and, if the number is to be kept within reason, each detector must be fairly sensitive. On the other hand, the detectors must not respond to the normal changes of radiation background due to the movement of radioactive materials about the plant. When an accident occurs the radiation levels will usually be sufficient to trigger more than one of the detectors and they can thus be used not only to sound an evacuation warning but, if they are linked to a display in a central control room, they may also be used to indicate the general area of the accident. More precise location of the accident can be achieved by using portable detectors, usually conventional health instruments.

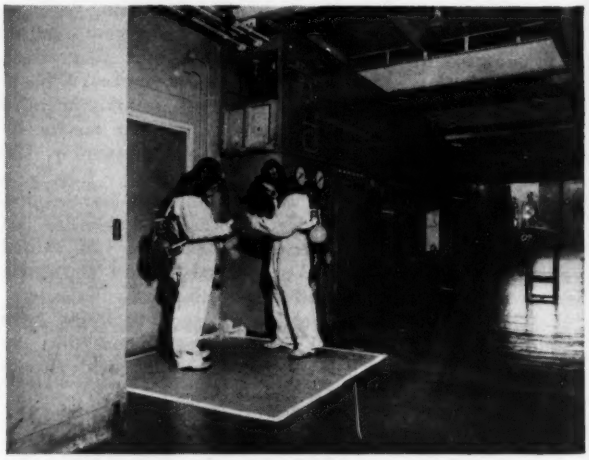
Neither of these methods is able to locate the accident with sufficient speed to allow any guidance to be given to the people who have to evacuate the plant. They merely hear a warning which they have been trained to recognize as meaning "Get out fast by the nearest route." Attention can be given to the planning of these routes so that they do not pass close to obvious danger spots, but, in many plants, it seems inevitable that some people will move towards the centre of the accident in making their escape. In the Oak Ridge accident, this happened to two of the workers in the vicinity of the accident. It may be possible to devise complex equipment which will provide more detailed instructions to the evacuating staff but it is not by any means certain that this would be desirable. Even if the nuclear reaction is complete in a fraction of a second, a substantial fraction of the total radiation dose is delivered in the next few seconds by the short lived fission products and immediate rapid evacuation is valuable. The need to choose between alternative routes on the basis of a display, presumably visual, might well cause small delays and increased radiation doses. The primary need is for a simple and forceful warning which produces an immediate reaction.

Identification of Exposed Personnel

In many cases, where the source of the accident is obvious, there will be little difficulty in deciding who has been exposed and the total number may well be small enough to allow them all to be studied in detail. In an accident on a process plant, without any obvious focus, the initial emphasis will rightly have been on evacuation and there may be well over 1,000 people involved, none of them knowing where the accident has occurred. If the injured are to receive early treatment and if the others are to be given early reassurance, a rapid and reliable indicator of exposure is a necessity. Fortunately, the radiation from a criticality accident always includes neutrons and even if these are predominantly fast, as they may well be, some of them will be thermalized in the body so that a suitable foil of the type used for measuring thermal neutron fluxes can be used as an indicator. Indium is an excellent material for this purpose and has such a high cross section that simple portable instruments can be used to check either the beta or the gamma activity without withdrawing the foil from the wearer. In this way 12 exposed people out of a total of 1,200 checked were identified in less than two hours from the time of the accident at Oak Ridge.

The half life of the indium isotope formed by neutron capture is only 54 minutes and the Oak Ridge experience suggests that a supplementary foil of gold would be useful and would allow a second, less urgent, check to be made. This would eliminate any chance of missing an activated foil in the period of inevitable confusion immediately following an evacuation.

At Oak Ridge, everyone on the plant wears a security



Production plant, handling fissile materials in quantity, is heavily shielded and only limited access is possible. Rapid identification of an accident area presents problems.

Fast neutron monitor model NE 046 by General Radiological, Ltd., London.

badge and the foils are part of the badge. In other establishments, the foils can be included in the protective clothing, issued as a special badge or locket or they can form part of a conventional film badge. In the last case it is important to see that activation of the indium does not cause appreciable exposure of the film.

Estimation of Radiation Dose

Radiation medicine has now passed beyond the stage where the treatment for acute radiation injury was based solely on the relief of symptoms as they appeared. Complete rest and the use of antibiotics to combat infection can be applied without any knowledge of the radiation dose incurred. However, one of the most recent treatments involves the injection of human bone marrow from a donor. Such an injection results in a dangerous reaction if the patient's bone marrow is uninjured, but this reaction is likely to be less severe if the patient's marrow has been severely damaged by radiation. The donor has to undergo repeated bone punctures requiring a general anaesthetic. Clearly, even if further experience confirms the value of such treatment, it should not be applied unless there is evidence that the radiation dose has been large enough to cause severe and dangerous damage to the bone marrow, but not so large that death will result from damage to other organs. Medical symptoms alone do not give information which is either sufficiently precise or sufficiently early to give the patient the best chance of recovery and so physical methods of dosimetry are also required.

The dosimetry problems are formidable. The radiation is a mixture of gamma rays with thermal and fast neutrons, the energy spectrum of which is dependent on the form of the accident and on the absorbing and scattering materials surrounding it. These radiations are differentially absorbed by the body so that there is no simple relationship between the free-air dose, the surface dose and the absorbed dose in the body. A further uncertainty is introduced by the lack of knowledge of the relative biological effectiveness of large acute doses of neutrons. The R.B.E. for chronic doses is taken to be ten but this is generally thought to be too high for acute doses and the figure used to interpret the Oak Ridge exposures was two. Research is still going on into the best combination of methods of measurement and it is not yet possible to arrive at any detailed conclusions. It is, however, possible to indicate some of the general methods which are being considered—some of which have already been used.

Almost any method of dosimetry will be improved if information can be provided about the energy spectrum and neutron to gamma ratio of the incident radiation. These can be studied in advance by considering the various types of assembly in which an accident is possible and discovering the spectrum of radiation emitted either by calculation or by experiments in which similar assemblies are made critical under controlled conditions while careful radiation measurements are carried out. In the event of an accident these results may not be reliable because of the modifying action of local shielding or scattering materials, and additional information can be obtained by installing a network of spectrum measuring devices throughout the vulnerable areas of a plant. A number of such devices suitable for measuring neutron spectra have been reported, the most useful being that described by Hurst[4]. The gamma spectrum is less important since it is relatively easier to take measurements of gamma dose independent of gamma energy. The neutron devices are resonance or threshold detectors which become radioactive when irradiated by neutrons at or above certain energy. The use of a series of such materials allows a spectrum of fast neutrons to be assessed. Unfortunately, the materials which give reasonable sensitivity at suitable energies are expensive. They include plutonium 239, neptunium 237, and separated uranium 238. They are surrounded by pure boron 10 to eliminate the effects of low energy neutrons. Only sulphur, which is converted to phosphorus 32 by neutrons above 3 MeV, is both suitable and cheap. Thermal neutrons, on the other hand, can be measured easily and cheaply with foils of indium, gold or tantalum. In all these cases the final measurement depends on an estimation of the activity of the irradiated material and can be done with a simple beta counter or a gamma scintillation counter.

Measurements with installed equipment give little or no information about the doses to individuals because it is rare for anyone's position to be known with sufficient precision and because the rate of movement of the people nearest the incident will affect their total dose considerably. In some cases conventional personnel monitoring devices will be worn and these will give some information. They are, however, designed to give results in the dose range up to a few rads and are unsatisfactory for higher doses. The most promising methods for doses up to 1,000 rads use either a film pack containing several emulsions of different sensitivity or a sensitized glass which develops a characteristic fluorescence as a result of irradiation[5]. The measurement of the gamma radiation at the point at which the device is worn is thus becoming fairly straightforward. This measurement is of the dose at the surface of the body and must be corrected to give the free-air dose. Unfortunately this correction depends on the orientation of the wearer relative to the source of radiation and this is not, in general, known. The extent of the uncertainty depends on the extent

Avo, Ltd., manufacture this portable monitor with scale calibrated from 0 to 100 mr/h and 0 to 5 r/h.

to which the radiation has been scattered but the total range may well cover a factor of three.

The measurement of the neutron dose can be tackled in two ways. Personnel monitors can be developed for thermal and fast neutrons but, in practice, considerations of size and weight prevent the fast neutron measurement by threshold detectors from being at all precise. Nuclear track emulsions can be used at the lower doses but become fogged and unreadable at doses of hundreds of rads. In any case the effect of orientation will be severe and may introduce an uncertainty by a factor of as much as 10. The second method is to measure the induced activity of the body itself. A neutron entering the body is slowed down by collisions with the nuclei of atoms and eventually either it is captured or it escapes. Snyder and Neufeld have shown that the probability of capture is almost independent of neutron energy above the thermal region and that this probability is about 0.4. Most of the captured neutrons are captured in hydrogen but about one in a thousand is captured in sodium, leading to the formation of sodium-24. This isotope has a half-life of 15 hours and emits beta particles with a maximum energy of 1.4 MeV and two gamma rays in cascade (1.4 and 2.8 MeV). Sodium is fairly uniformly distributed through the body and the neutron-induced activity can be measured either by counting a body fluid or by whole body counting. At Oak Ridge, the most satisfactory results were obtained with blood samples but analysis of urine may be used as an alternative provided that inactive sodium determinations are also carried out and provided that the first voiding, which will be unrepresentative, is neglected. If most of the neutrons are above thermal energies, the sodium-24 measurement gives an estimate of the total integrated flux of fast neutrons striking the body. This cannot be directly interpreted in terms of dose because the dose delivered by fast neutrons depends not only on the integrated flux but also on the neutron energy. The importance of the installed threshold detectors and of the advanced estimates of the neutron spectrum now becomes clear. With the information on the neutron spectrum which they provide, the measurement of the sodium activity gives a sound measurement of the neutron dose regardless of the orientation of the person and the radiation source. The results of the personnel gamma monitors can also be checked if the installed units include a dosimeter to measure the ratio of the neutron to the gamma dose. Further cross-checks are possible if the installed units include some of the elements of the personnel dosimeter.

In the Oak Ridge accident the sodium-24 measurement was made to provide an estimate of the dose from all radiations by a calibration experiment which repeated the assembly under controlled conditions. The repeat assembly was operated as a low power reactor while precision measurements of gamma dose, neutron dose, and neutron spectrum were made. At the same time a burro (or mule) was irradiated and used to provide calibrated samples of sodium-24 in blood. In view of the fact that the calibration data are required within one or two days of the accident it is clearly unwise to rely on setting up a repeat of the accidental assembly.

In summary, the successful handling of a criticality accident depends on a combination of the following methods.

1. Immediate detection of the accident and sounding of an evacuation warning.
2. Rapid identification of the exposed personnel.
3. Preliminary estimation of the neutron spectra and neutron to gamma ratios for a wide range of possible assemblies.
4. Installation of devices to measure these parameters at various places round sites of potential accidents.
5. Provision of personnel dosimeters.
6. Measurement of the induced sodium-24 activity in the body.

The first two of these methods are of vital importance and satisfactory techniques are already available. The remaining four methods are concerned with the measurement of radiation doses and are still the subject of further study in this country and in the United States. It is still too soon to be dogmatic about the best overall system of dosimetry but it seems probable that a personnel gamma dosimeter coupled with neutron measurements from the sodium-24 determinations will give the most satisfactory solution.

All these studies are important because they contribute to the reduction of the injuries from criticality accidents. Even more important, however, is the problem of ensuring that criticality accidents, already rare, become extinct.

REFERENCES

1. *See below.*
2. Gillieson, A. H., "The Prevention of Unwanted Criticality," *Nuclear Engineering*," Aug 1956, 1, 5., p. 186.
3. Patton, F. S. *et al.*, "Accidental Radiation Excursion at the Y-12 Plant, June, 1958." *Oak Ridge Report*, Y-1234.
4. Hurst, G. S. *et al.*, "Techniques of Measuring Neutron Spectra with Threshold Detectors—Tissue Dose Determination," *Rev. Sci. Instr.* March, 1956. 27, 3, p. 1953.
5. Proctor, B. E. *et al.*, "Studies of Glass Dosimeters," *Final Report* NYO 3345.
6. Snyder, W. S. and Neufeld, J., "Tabulated Depth Dose Curves in Tissue for Broad Beams of Fast Neutrons," *Oak Ridge Report* ORNL 1872.

Criticality Accident in Yugoslavia

FURTHER details have now been published[1] of the radiation accident at the Boris Kidrich Institute in Belgrade on October 15, 1958. The incident occurred when the Institute's zero energy heavy water natural uranium fuelled reactor became critical during a subcritical experiment. Six personnel in the immediate neighbourhood who received strong doses of radiation were treated at the Curie hospital in Paris: one of the six subsequently died.

The report reveals that during the course of the experiment there was no instrument for radiation alarm or automatic control of the reactor. The reactor became critical because of an uncontrolled rise in the level of heavy water in the reactor tank.

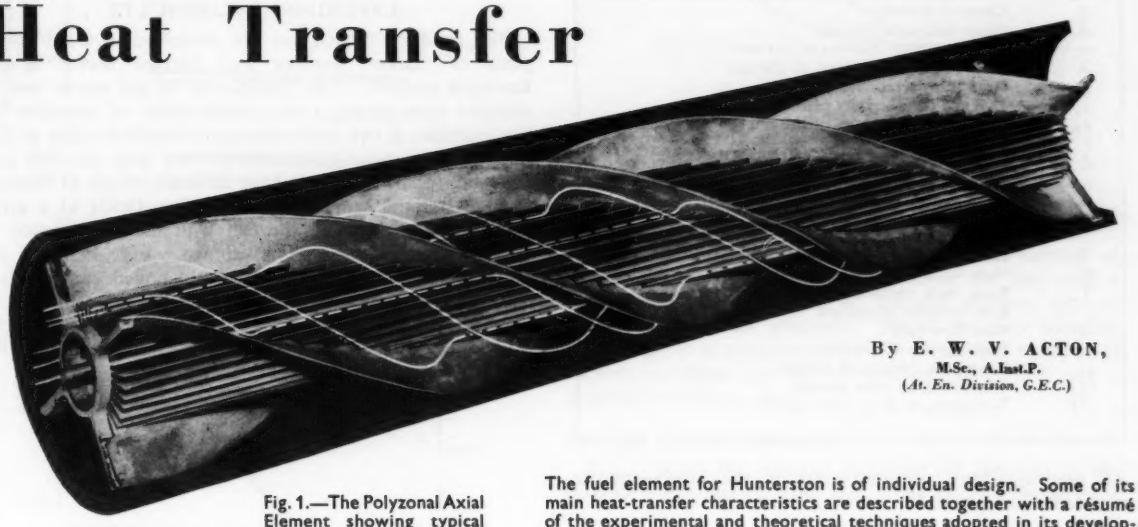
Amongst other things, the principle of interlocking controls was not fully realized and it was possible to put the reactor into operation without ensuring that the automatic control rod system would operate at a predetermined rise in the level of radioactivity.

In the absence of automatic alarm devices or protective controls the personnel in the immediate vicinity of the reactor were only aware of the critical state by the ozone smell. The actual power rise of the reactor was first known ten minutes later when a considerable increase in gamma radiation was shown on the automatic activity recorders located some 540 metres away from the reactor itself.

REFERENCE

[1] Bulletin of the Boris Kidrich Institute of Nuclear Sciences, Belgrade, March, 1959.

Hunterston Fuel Elements Heat Transfer



By E. W. V. ACTON,
M.Sc., A.Inst.P.
(*At. En. Division, G.E.C.*)

Fig. 1.—The Polyzonal Axial Element showing typical gas flow paths.

The fuel element for Hunterston is of individual design. Some of its main heat-transfer characteristics are described together with a résumé of the experimental and theoretical techniques adopted in its development.

THREE basically different types of fuel element are currently in or nearing production for the British gas-cooled industrial nuclear power reactors. These fuel elements are:—

(a) the Calder Hall type, which is transversely finned;

(b) the polyzonal spiral type, which has spiral fins together with axial flow separators or splitters;

(c) the polyzonal axial, or Hunterston type, which has axial fins together with spiral flow separators or swirlers.

The Calder and polyzonal spiral types have been reported previously[1, 2, 3]; the present article deals essentially with the polyzonal axial type of fuel element, and is mainly concerned with its thermodynamic design features. A previous paper by Wootton and Dennis[4] has described the development of some of its mechanical features.

Both the polyzonal spiral element and the Hunterston element use the principle of coolant cross-mixing between the fuel element and channel wall. With the polyzonal spiral type (see Fig. 2) coolant enters between the fins and starts to spiral along their surfaces, meets the splitter and continues to the channel wall, returns to the fins, and repeats the pattern. The gas thus describes a helical path in the channel sector bounded by the channel wall, the splitters, and the can. The helix has its axis parallel to the axis of the element.

With the Hunterston element, the coolant follows the fins (as shown in Fig 1) until it meets a spiral swirler, when it is deflected, spirals along the channel wall, and returns to repeat the pattern between the fins. As the two types of fuel element use spiral gas flow, it might be expected that any axial variation in the temperature of the can wall (brought about by the entrance conditions on the flow pattern), giving rise to similar axial variation in heat transfer coefficient, would be similar. However, whereas for the polyzonal spiral the corresponding variation in Stanton number appears to be about $\pm 8\%$ (see Fig. 6 (*a*) of ref. 3), for the Hunterston type the value is considerably smaller. This form of temperature variation is one of the systematic design features which affect the quoted maximum temperature of the can.

Experimental Procedure

In order to examine the flow patterns over fuel-element surfaces experiments have been made with water models, and to find the heat-transfer and pressure-drop characteristics, initial tests are made in air rigs at substantially atmospheric pressure, followed by tests in pressurized equipment (Fig. 3), using either air or carbon dioxide[5, 6].

The cans are assembled on a thin-walled stainless-steel heater tube which is insulated electrically by means of a very thin (0·0015 in.-0·002 in.) ceramic glaze, and is heated by passing heavy electric currents (a.c. in the case of atmospheric rigs and d.c. in the case of the loop) at low voltage. Chromel-alumel thermocouples are arc welded by condenser discharge on to the root surface of the elements and further thermocouples are attached along the axis of the test can at 3-in. intervals. Shielded thermocouples measure inlet and outlet gas temperatures.

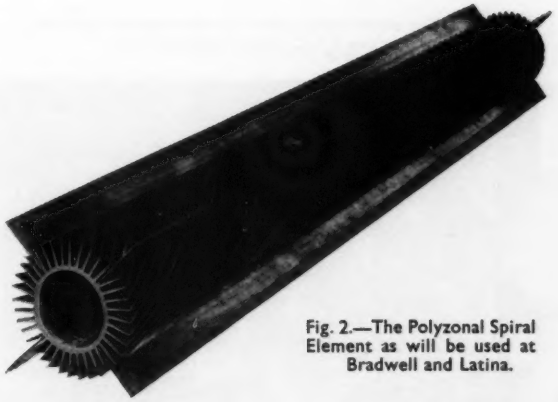


Fig. 2.—The Polyzonal Spiral Element as will be used at Bradwell and Latina.

NOMENCLATURE

a	Cross sectional area for flow
A	Area of heat release
c	Mean specific heat of coolant at constant pressure
d_c	Channel diameter
d_e	Mean hydraulic diameter
d_f	Diameter over the fins of the can
d_r	Diameter over the root of the can
h	Heat-transfer coefficient
k_g	Thermal conductivity of the coolant film
k_m	Thermal conductivity of the fins
l	Swirler lead
L	Length of section
n	Number of fins
p_m	Mean pressure over section
Q	Heat release from section
t	Mean fin thickness
T_c	Can surface temperature at the base
T_g	Mean local bulk coolant temperature
T_m	Mean bulk coolant temperature over section
v	Bulk velocity of coolant
W	Mass flow rate
ρ	Bulk density of coolant
ρ_m	Mean bulk density of coolant
Δp	Pressure drop over section
ΔT	Temperature drop over section

All thermovoltages are measured by the potentiometric null-deflection method.

Derived Values

When the apparatus reaches steady temperature conditions, readings are taken of the various functions and the results used to obtain Stanton numbers and the corresponding Reynolds numbers. The heat flux is deduced from the electrical power input to the test section; the mean surface temperature at the can root is calculated from 10 measurements in selected positions on the test section, the bulk gas temperatures local to these positions on the can are deduced by the heat-balance method. The Stanton number is defined as:—

$$St = h/\rho vc \ldots \quad (1)$$

The convention that has been used in deriving h and v in this work assumes that the area for heat-transfer is that of an imaginary sheath enclosing the fin tips, associated with a consistent mean hydraulic diameter.

Expressing the Stanton number in the form:—

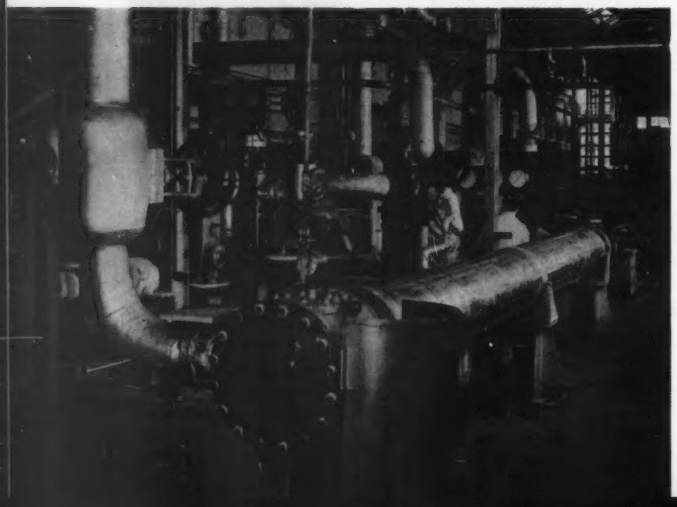
$$St = Qa/A(T_c - T_g)Wc \ldots \quad (2)$$

its values can be calculated from the experimental readings.

The friction factor f is measured and evaluated using the relationship[6]:—

$$f = \frac{d_e}{2L}\left(\frac{\Delta p}{\rho_m v^2} - \frac{\Delta T}{T_m} - \frac{\Delta p}{p_m}\right) \ldots \quad (3)$$

Fig. 3.—The pressurized carbon dioxide heat transfer test rig at the G.E.C.'s Erith Laboratories.



where again the same convention for v applies, and d_e, the mean hydraulic diameter, is defined as four times the flow cross-sectional area divided by the "wetted" perimeter.

EXPERIMENTAL RESULTS

The results for each can are presented in the form of plots of Stanton number and friction factor against Reynolds number. The significance of the curves can be deduced most simply from consideration of equation (2). For example, if two fuel elements of identical value of a/A (i.e., with the same cross-sectional flow area per unit area available for heat release) have different values of Stanton number but the same value of friction factor at a given Reynolds number, then the can with the larger value of Stanton number has the advantage. Fig. 4 shows the results for a Calder-type transversely finned can which is one of the many types tested during development.

In using extended surfaces of the Hunterston type for the design of reactors, it is necessary also to examine the

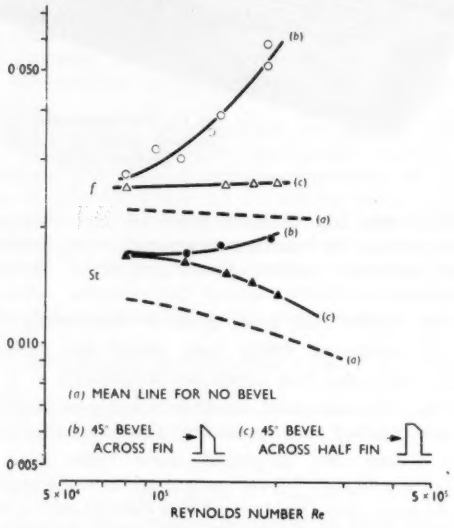


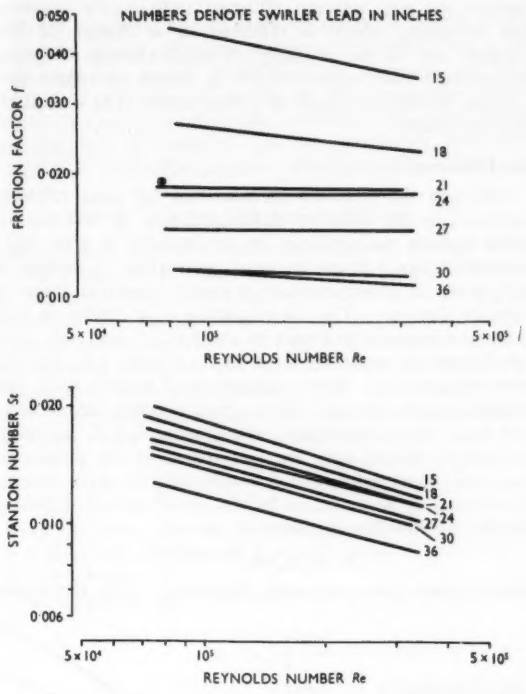
Fig. 4.—Performance curves for a transversely finned can showing the influence of fin chamfering which simulates element distortion.

effects of various dimensions when combined so that a given maximum volume of Magnox is not exceeded. Some of the variables that need to be taken into account are as follows:—

(a) lead and number of swirlers;
(b) outer diameter of can for a given channel diameter;
(c) channel diameter for a given can size;
(d) number and cross-section of fins;
(e) tolerances in manufacture.

Swirler Lead and Number

The effect of varying the lead of the swirlers, as might be expected, is to alter the Stanton number and friction factor for the whole range of Reynolds numbers covered by the tests. Fig. 5 shows the results of some tests made on a 36-fin can in a pressurized loop. As the lead of the swirlers is decreased, both the Stanton number and friction factor increase, and the right hand graph of Stanton number and friction factor against lead indicates (for the size of can tested) the sensitivity of the friction factor to lead, for values less than about 27 in. Over the same range



of lead the Stanton number rises only steadily, and so for a given size of can and channel there is an optimum lead corresponding to an optimum circulator power.

Fig. 6 shows the effect of increasing the number of swirlers on an otherwise similar system. Both the friction factor and Stanton number rise with increasing Reynolds number, but these curves have been obtained without

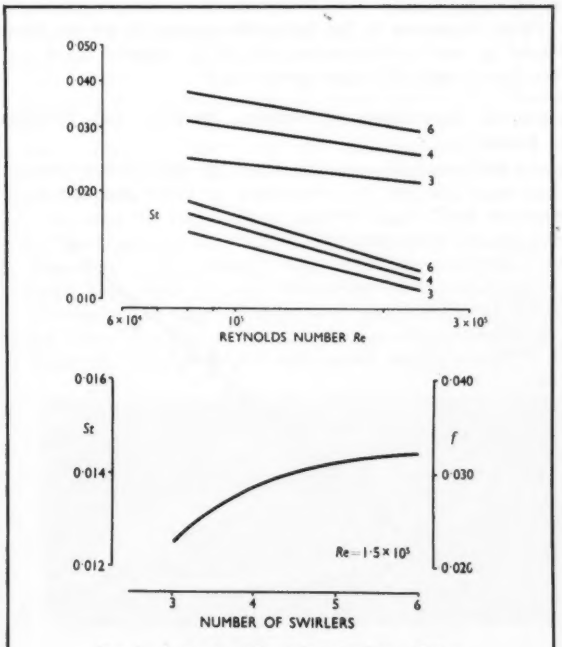


Fig. 6.—Influence of swirler number. Other dimensions as in Fig. 5.

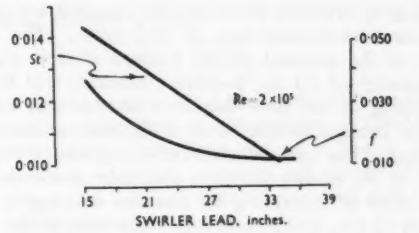


Fig. 5.—Effects of swirler lead. Can o.d.: 2·35 in.; root dia.: 1·30 in.; No. of fins: 36; channel bore: 4·0 in.

limiting the volume of Magnox to a constant value. If the total system has to have a constant volume of Magnox per unit length of channel, then increasing the number of swirlers means reducing the thickness of the fins, with a corresponding degradation of Stanton number due to reduction of the fin efficiency. Hence the final selection for design is a compromise. The minimum number of swirlers to create the desired flow pattern is two, and a practical maximum four.

Can and Channel Diameters

Fig. 7 shows the effect of changing the diameter of the cans in a channel of fixed size. The friction factor at a

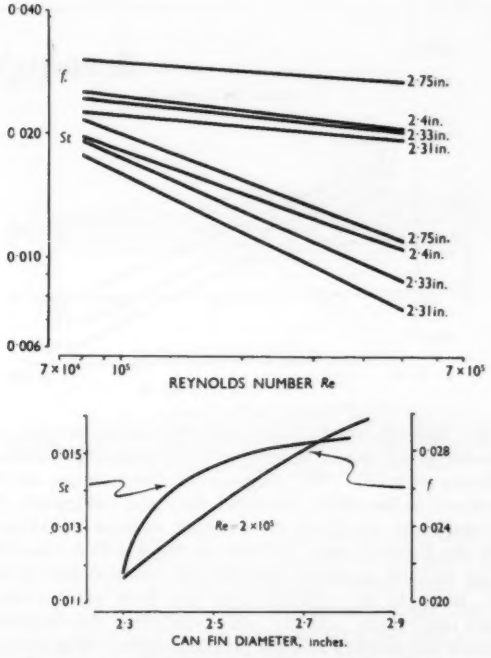


Fig. 7.—Performance with varying fin diameter. Root dia.: 1·30 in.; No. of fins: 48; No. of swirlers: 4; swirler lead: 24 in.: channel bore: 4·0 in.

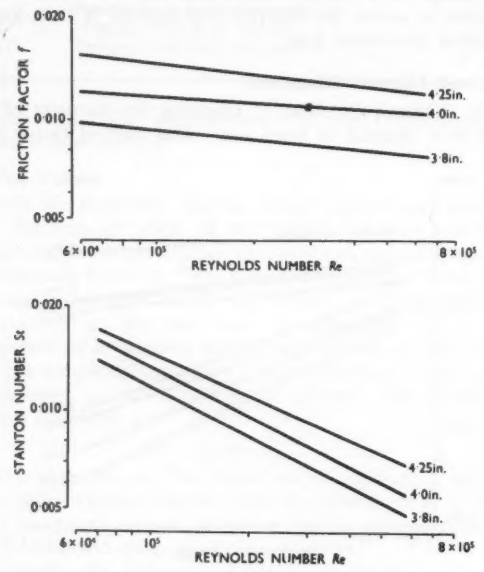
Reynolds number of 2×10^5 rises steeply as the outer diameter increases, with the Stanton number levelling off at above 2·7 in. It is evident that the rotational-flow characteristic is becoming very damped when the fins approach closer than about 0·65 in. to the channel wall. This distance appears to be significantly less than for the polyzonal spiral fuel element and leads to slightly larger thermal outputs from the reactor when Hunterston-type fuel elements are used in the region beyond the flattened zone of the core. The gain is due to a reduction in axial

streaming of neutrons when smaller channels are used, for the same fuel-element size, in this zone. The marked change in the gradient of the Stanton number around a can diameter of 2·4 in., however, indicates that the onset of damping of the flow may well start in this region; it does not become serious until a diameter above 2·75 in. is reached. The cans selected for this graph have 48 fins, instead of 36, as they illustrate this point more clearly.

The effect of increasing the channel size, again using a can with 48 fins, is shown in Fig. 8 (the lead of the swirlers is not the same as for Fig. 7). The trend, as might be expected, is for both Stanton number and friction factor to increase with increasing channel size.

Number and Size of Fins

The effect of increasing the number of fins is to increase the Stanton number for a given Reynolds number, with a rather smaller increase in friction factor. The distance between adjacent fins at which the gas flow becomes restricted appears to be less than the smallest gap that manufacturers have been able to make by extrusion methods to date. Any increase in the number of fins, therefore, is beneficial provided they are sufficiently thin to satisfy the condition of constant volume of Magnox.



As the swirlers have to constrain the gas flow essentially within its own quadrant between the fins and the channel wall, it might be expected that the flow pattern would deteriorate fairly rapidly on increasing the clearance between the swirlers and the graphite sleeve. The opposite has been found to be true and no marked change either in Stanton number or friction factor has been found for clearance up to a value of 0.063 in. The effects of manufacturing tolerances on the outer diameter of the can and bore of the channel may be seen from Figs. 7 and 8 to be quite significant, and some judgment is required before a choice is made for a particular design study.

Effects of Irradiation

As far as heat transfer is concerned the prime effect of irradiation consists of swelling of the fuel. The radial extension decreases the hydraulic diameter of the system without increasing the heat-transfer area other than by the small amount at the root of the fins. The elongation reduces the gap between adjacent individually supported fuel elements, which is reflected in a change of local pressure loss in the coolant. A small change of lead of the swirlers also occurs, and it is hoped to report some of these findings in detail at a later date. The cumulative effect is small.

Fin Efficiency

Although the effective surface area for heat release is increased by the addition of fins, the gain in heat removal is not directly proportional to the increase in area, but is somewhat less. Since the heat generation is within the fuel, there is a temperature gradient outwards from the roots of the fins. The fin efficiency of a system is unity if the temperature gradient in the fins is zero; the actual value depends upon the heat flux, coolant, can material, and temperature. When experimental results have been obtained from the air rigs at low coolant temperatures and heat fluxes, therefore, some correction is necessary. In general, design data are established in the pressurized loop using essentially reactor conditions, but data obtained otherwise may be corrected by the use of curves of Stanton number against the quantity:—

$$K\,(k_g/k_m)^c Re^{[a+c(a+1)]},$$

where a and c are constants depending upon the experimental conditions and lying between 0 and 1, and K is a geometrical factor.

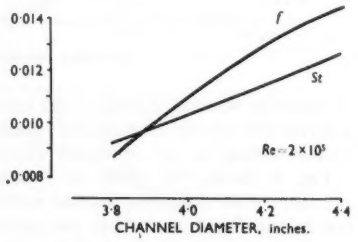


Fig. 8.— Channel size influence. Can o.d.: 2·75 in.; root dia.: 1·30 in. No. of fins: 48; No. of swirlers: 4; lead: 36 in.

This correction to the Reynolds number is of the same form as that of Fortescue and Hall, namely $Re\ k_g/k_m$, becoming identical when $a=0$, $c=1$.

General Correlation of Stanton Number and Friction Factor

In the design of a reactor, when the type of fuel element has been selected it is necessary to know the effects of

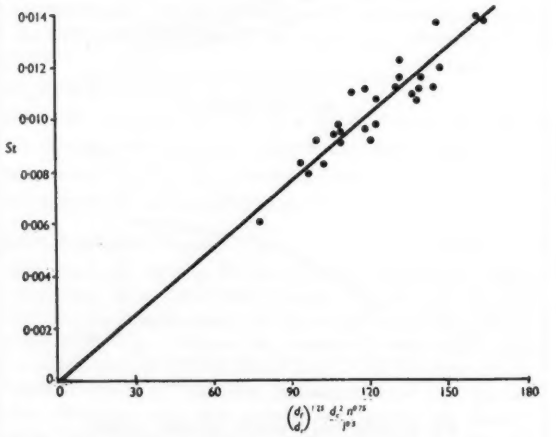


Fig. 9.—Correlation for Stanton number at a Reynolds number of 3.10^5.

different combinations of sizes in order to obtain a configuration giving optimum performance. With this object Pickering[6] has found it possible to correlate the large number of experimental results for the Hunterston type of can by two empirical formulæ, one referring to the Stanton number and the other to the friction factor, both as a function of Reynolds number. The method was to assume that:—

$$St \propto (d_e)^A (d_f)^B (d_r)^C (n)^D (l)^E (t)^F (\phi)^G,$$

where A, B, C, D, E, F, G are constants over a range of *Re*.

The values of the indices were found by trial and error to obtain the minimum standard deviation, over ranges of Reynolds number suitable for use in design. Since a constant mass of can per unit length of channel is required, the effect of change in the fin thickness t was found to be insignificant and so is ignored. Over the range of values of fin taper tested, the effect of variation was also found to be small. As a result it was found that:—

$$St \propto \left(\frac{d_f}{d_r}\right)^{1\cdot75} \frac{d_e^2\, n^{0\cdot75}}{l^{0\cdot5}}$$

Fig. 9 shows a plot of St against the function in brackets at a Reynolds number of 3×10^5, using variations in all the dimensions.

A correlation has been obtained for the friction factor in a similar manner, giving:—

$$f \propto \frac{d_e^2\, d_f^{1\cdot6}}{d_r^{1\cdot3}\, l}.$$

It will be noted that, in general, the friction factor is substantially independent of the number of fins, and this holds for significant variations, e.g., $\pm$ 6 fins.

The application of these curves is self evident and forms a useful basis in selecting suitable sizes of can for new station design studies.

ACKNOWLEDGEMENTS

This article summarizes just a small part of the work that has gone into the heat-transfer development of the Hunterston type of fuel element. Thanks are due to all those colleagues who have contributed to its content, in particular, P. S. Thompson and G. R. Hatton, and to other members of the Atomic Energy Division at Erith in the Reactor Heat Transfer Section.

REFERENCES

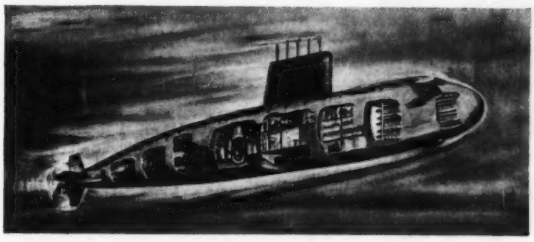
1. Fortescue, P. and Hall, W. B., "Heat Transfer Experiments on the Fuel Element," *J.B.N.E.C.*, 1957, pp. 1–15.
2. Ritz, H. L., "The Polyzonal Spiral Fuel Element," 2nd Int. Conf. on the Peaceful Uses of At. En., 1958, *P*/48.
3. Hughes, D. F. and Slack, M. R., "A Correlation of Heat Transfer for Finned Fuel Elements for Carbon Dioxide Reactors," 2nd Int. Conf. on the Peaceful Uses of At. En., 1958, *P*/38.
4. Wootton, K. J. and Dennis, W. E., "The Development of the Hunterston Fuel Element," 2nd Int. Conf. on the Peaceful Uses of At. En., 1958, *P*/1523.
5. Skipper, R. G. S. and Wootton, K. J., "Thermal Resistance between Uranium and Can." 2nd Int. Conf. on the Peaceful Uses of At. En., 1958, *P*/87.
6. Pickering, A. R., "Correlation of Heat Transfer and Pressure Drop Data for G.E.C. Type Fuel Elements," *Internal memorandum*, 1959.

U.S.S. *Skipjack*

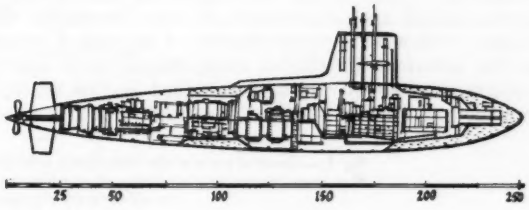
THE PWR-powered U.S. submarine *Skipjack* with the hydrodynamic hull paid its first visit to England on August 14 when she docked at Portland. In addition to the American crew of 95, under Commander W. W. Behrens, Jr., she carried the designate commander of the *Nautilus*, Commander B. E. P. Sambourne, who has been gaining experience in the handling of this remarkable craft which is believed capable of speeds in excess of 35 knots.

With a length of 252 ft and a beam of 31 ft the ship has a submerged displacement of 3,500 tons. Her construction was authorized for 1956 and begun at the Electric Boat Division of General Dynamics on May 29 of that year. Just two years later she was launched, began sea trials in March of this year, and was finally commissioned on April 15.

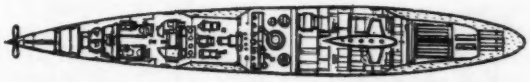
Between the single screw, and the single PWR developed by Westinghouse (the S5W), the propulsion equipment is duplicated. The primary coolant system comprises two loops each with its own pressurizer and shell-tube heat exchanger, the water in each loop being circulated through the tubes by a pair of canned pumps, a third remaining as stand-by. The two heat exchangers supply steam to the two main propulsion turbines and the ship's service turbo-generator sets. The general lay-out of the plant can be seen from the sectioned drawings. More than adequate shielding is provided and is augmented on the living quarters side by fuel oil tanks athwart the ship extending to the top of the pressure vessel.



Artist's impression of the *Dreadnought*. Although no date has been given for her completion repeated statements have been made that the construction period would be "surprisingly short."



Sketches of the *Skipjack* sections.



Emergency drive is provided through two battery-powered electric motors mounted integrally on the propeller shaft. In addition they can be supplied by small diesel or motor generator sets.

Both manual and automatic control of the reactor is provided, but normal steam demands are met by the inherent negative temperature coefficient of the reactor.

The *Dreadnought*, although incorporating identical propulsion machinery, will be slightly different hydrodynamically, the most obvious change being the transfer of the diving planes from the sail (conning tower) to the bows of the vessel. Performance-wise there is unlikely to be a great deal to choose between the two vessels.

The Queen Mary College Uranium-Water Subcritical Assembly

By W. MURGATROYD, M.A., Ph.D.,
W. K. MANSFIELD, B.Sc.,
and J. M. KIM, B.Sc. (Seoul)

A uranium-water subcritical assembly has been set up which can be used for the study of static and transient phenomena. The new laboratory represents an important addition to the facilities available to post-graduate nuclear engineers at Queen Mary College.

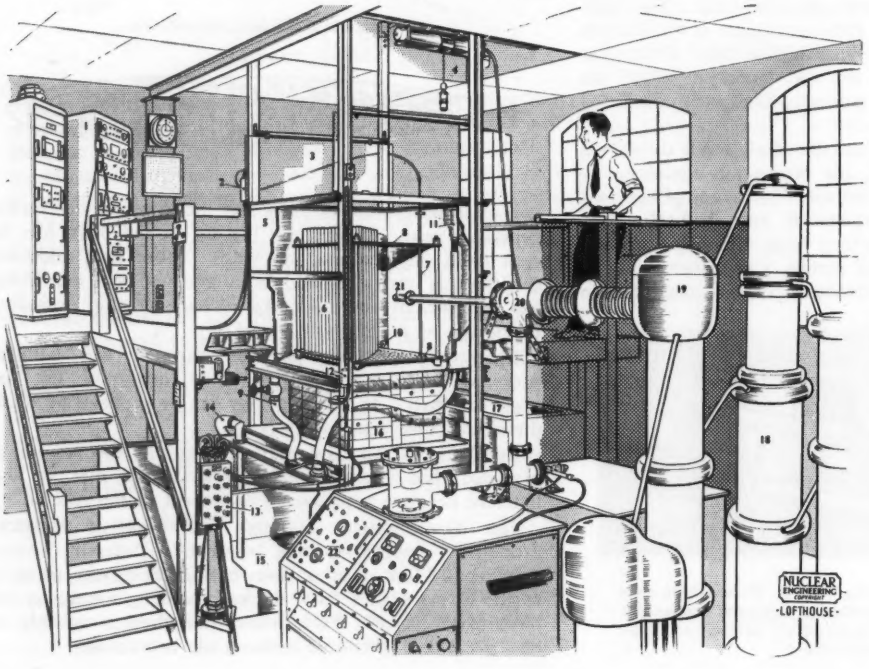
AN optional introductory course on nuclear engineering has been available since 1951 at Queen Mary College to final year electrical and mechanical engineering undergraduates. The supporting laboratory work has consisted of experiments demonstrating the principles of particle counting, shielding, neutron activation of materials and the diffusion and multiplication of neutrons in water, boric acid and uranyl nitrate solution. The original function of the present laboratory was to provide experimental facilities for this undergraduate course, and for research on engineering aspects of nuclear particle generators.

Since 1956 the scope of the research and teaching programmes has been widened to include other aspects of nuclear engineering but emphasis is still placed on " applied nucleonics "—that is, on the engineering aspects of the production of nuclear particles and their interaction with matter. The most important feature of this field is a study of the behaviour of neutrons inside reactor cores, and the subcritical assembly which is described in this article is regarded as the first stage of this study. This is a new engineering research activity for a British University and the initial object of the present assembly is to enable staff and research workers to get first-hand experience of the problems involved. In view of the newness and importance of the subject the Department of Scientific and Industrial Research agreed to support the project and the assembly has been built with funds supplied by that Department.

In 1958 a post-graduate course in nuclear engineering was started. In this course emphasis is placed on applied nucleonics, and suitable experimental facilities are being provided. Great importance is attached to experiments and minor research projects which are sufficiently ambitious to confront students with genuine experimental difficulties. Such experiments and projects are more realistic and stimulating when carried out in conjunction with research which is in progress. In this connection the subcritical assembly has already proved a very valuable adjunct to the post-graduate course.

Normally a sub-critical assembly comprises a small portion

Fig. 1.—General view of the laboratory with the accelerator in the right foreground. The core comprising an array of vertical natural uranium elements is supported in its tank by a graphite pedestal.



KEY

1. Flux monitoring instruments
2. BF_3 counter pre-amplifier
3. Perspex covers
4. Martonair hoist
5. Aluminium tank
6. Fuel elements
7. BF_3 counter probe
8. Lattice plates
9. Outlet dump line
10. Inlet line
11. Overflow
12. Outlet to water purification plant
13. Mixed bed demineralizing plant
14. Pump suction line
15. Dump tank
16. Graphite pedestal
17. Fuel element store
18. 250 kV rectifier set
19. Ion source
20. Accelerator tube
21. Target
22. Control console for accelerator

of critical chain-reacting assembly upon which measurements may be made to provide a first estimate of critical size without incurring the cost or dangers associated with measurement upon a full-scale assembly. The choice of fuel for a University assembly is restricted at the present time to natural uranium, whence either heavy water, beryllium or graphite must be used as a moderator if potentially critical systems are to be studied. However, of these moderating materials, beryllium and graphite, being solid, lead to less flexible designs, and heavy water is considered too expensive a commodity for the initial phase at least. Apart from these considerations there is a real interest in the study of hydrogen moderated systems and the obvious choice of moderator is water. The fact that a natural uranium/water system cannot be made critical is of no significance to the present studies. Moreover an assembly designed for water can be used for studies of organic moderated systems. Operation at elevated temperatures can be simply achieved. If slightly-enriched uranium ($C_0 = 1.3$) should later become available safe approach-to-criticality experiments should also be possible.

Water is pumped from the lower tank up into the core tank by means of a stainless steel pump and allowed to run out of an overflow pipe whose height may be adjusted. The water used with the assembly is treated with a Permutit Mark 4F demineralizing plant and subsequently with a 3 in. dia. mixed-bed plant (Permutit, Type SM663). The treated water has less than 1 ppm dissolved solids and less than 0.01 ppm Fe. Such treatment is considered essential to reduce the corrosion of aluminium by the water. To decrease corrosion still further, 99.5% aluminium (copper content less than 0.02%) is used throughout and all aluminium surfaces are pickled first in NaOH and then nitric acid before rinsing in demineralized water. During operation the water is cycled continuously through the mixed-bed plant and its conductivity is monitored. Great care is taken to maintain the water pure; Perspex lids cover the tank, and filters are fitted to the ventilation plant. The water height is measured by means of an external level gauge. Provision is being made for the insertion of suitably-clad immersion heaters to enable temperature effects to be studied.

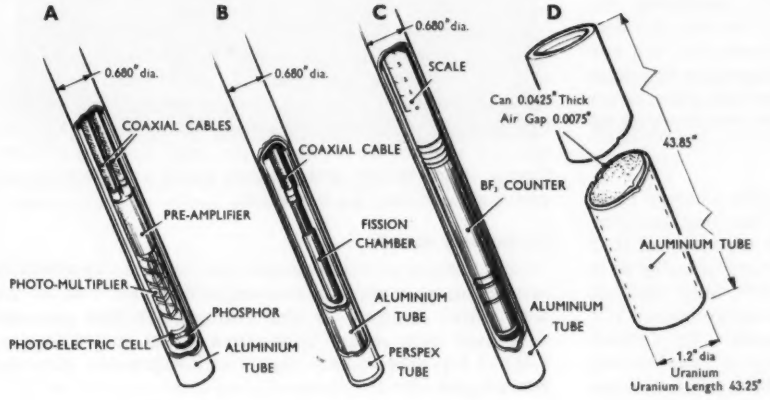


Fig. 2—Cut-away sections of the measuring probes and fuel element. A — Scintillation counter; B—Fission chamber; C—BF_3 counter; D—Natural uranium fuel slug canned in aluminium.

THE ASSEMBLY

Fig. 1 shows the completed assembly. It is seen to consist essentially of an aluminium core tank 4 ft 6 in. cube supported centrally upon a graphite pedestal and peripherally by a steel-angle tower. The graphite pedestal 2 ft 8 in.×2 ft 8 in.×2 ft high sits on a rubber mat on a ¼-in. steel base plate immediately above the aluminium dump tank which is 8 ft×4 ft 6 in.×3 ft high. The fuel elements (Fig. 2D), on loan from the U.K.AEA, are "as-cast" uranium bars, 1.2 in. dia. and trimmed off to 43.25 in. length. The uranium is sheathed in aluminium cans 0.040 in. thick. Up to 256 fuel elements, nearly four tons, can be loaded in a vertical position resting on the base of the core tank and positioned by pairs of aluminium lattice plates, ¼ in. thick and spaced 3 ft apart. The lattice plates were jig-drilled and reamered in the College instrument shop with a cell tolerance of better than 0.001 in. and an overall tolerance of 0.008 in. on the 16×16 element array. Plates for square and hexagonal lattices have been constructed giving moderator to uranium volume ratios of 1.25, 1.73, 2.50 and 3.20.

Since a change of lattice pitch involves moving nearly four tons of uranium, a Martonair hoist is mounted above the core tank on a trolley so that the fuel elements may be lowered directly into the fuel element store involving a minimum of manual labour.

Neutron Sources

To provide a sufficiently intense neutron flux for exponential experiments a neutron source strength of at least 10^7 n/sec is essential. This can be obtained from 1 curie Ra-Be, 3 curie Sb-Be or 4 curie Po-Be sources. The latter source is only a very weak γ-emitter and was therefore chosen in preference to the others requiring as it does very little shielding (about 1 ft of water). At the moment a 10 curie Po-Be source is in use and this, when placed in the centre of the graphite pedestal, gives an approximately uniform thermal neutron flux of 10^4 n/cm², sec at the base of the tank.

Measurement of the "fine-structure" flux within a single cell of the lattice requires a thermal flux of $10^7 - 10^8$ n/cm², sec i.e., equivalent to a source strength of $10^{10} - 10^{11}$ n/sec. Such a flux cannot be obtained practically, using radioactive sources and recourse must be had, either to the thermal column of a low-power research reactor, or to an artificial neutron source such as can be provided by an accelerator.

Adopting the latter course for reasons which will become apparent later, a 250-kV d.c. rectifier set has been erected adjacent to the assembly as shown in Fig. 1 and an accelerator tube and ion source are being developed to produce a 1 mA beam of deuterons. A yield in excess of 10^9 n/sec or

10^{10} n/sec is predicted from such a source for deuterium-zirconium and tritium-zirconium water-cooled targets respectively. It remains to be seen whether these yields can be maintained reasonably steady over the period of foil activation (~54 min for indium). Operation at these levels will require additional shielding not shown in Fig. 1.

It is also proposed to pulse the accelerator beam electronically to give a burst of neutrons lasting from a few to several hundred μsec. Observation of the decay rate of the transient will give information on the Laplacian of the assembly and also allow the transient response of the system to be studied.

Measuring devices

Four main types of flux measurement are being used:

(1) *Foil activation technique*

Two sets of double-sided foils have been made, each consisting of two ½-in. or ¼-in.-dia., 0.005-in.-thick indium stuck to both sides of an aluminium backing foil. One set, of ½ in. dia. is used for axial flux measurement, the other for the radial flux. The ½-in. set is stacked between Perspex spacers in a ¼-in. o.d. Perspex tube which can be positioned by suitable pairs of holes in the lattice plates. The ¼-in. set is stuck to Perspex stringers with Lassothene; the stringers in turn are inserted horizontally between the fuel elements and stuck to them. Cadmium boxes for both sets have been constructed so that the epi-cadmium flux may also be determined. After irradiation the foils are counted by pairs of vertically opposed end window β-counters giving almost 2π geometry for each foil.

(2) *BF_3 Counters* (Fig. 2C)

Enriched BF_3 counters of ½ in. dia. (20th Century Electronics, Type 5EB 40/13) have proved the most sensitive thermal neutron flux detectors, having a sensitivity of 0.32 counts/sec per unit flux. The counters are screwed to a ½-in.-dia. thin-walled aluminium tube, 4 ft. long, through which is threaded the coaxial cable to the counter. The aluminium tube slides telescopically inside a blanked-off ¾-in. o.d. aluminium tube, 4 ft 6 in. long, to which it may be clamped by a lock-nut. The outer tube is located in one of the pairs of measuring holes in the lattice plates and the height of the counter is read off from a millimetre scale machined on the movable inner tube. The output of the BF_3 counter is fed via a pre-amplifier and linear amplifier to a conventional scaler.

(3) *Fission Chambers* (Fig. 2B)

A similar mounting technique to that described above is used with the ¼-in.-dia. fission chambers (20th Century Electronics, Type FC4/1000—U^{235} and U^{238}). Their sensitivities, 0.003 counts/sec per unit flux, are much less than the BF_3 counter but by using suitable filters it is hoped to learn something of the fast neutron flux within the core.

(4) *Scintillation counters* (Fig. 2A)

The smallest diameter photo-multiplier commercially available, the E.M.I. Type BMS 10/14, ¾ in. o.d., is too large for insertion between the fuel elements, water-moderated systems having a very closely-spaced lattice for optimum multiplication. For this reason it will be necessary to extract a fuel element from the lattice and use the vacated site for the photo-multiplier, phosphor and pre-amplifier. The scintillation counter can be made sensitive to neutrons of a variety of energies by the choice of a suitable phosphor* and this should provide a means of studying the neutron energy spectrum within the core. The scintillation counter also has a very rapid response time and is therefore better suited than the other detectors for analysing rapid variations of neutron flux caused by a pulsed neutron beam.

* We are indebted to Nash and Thompson for the supply of experimental phosphors containing samarium and gadolinium.

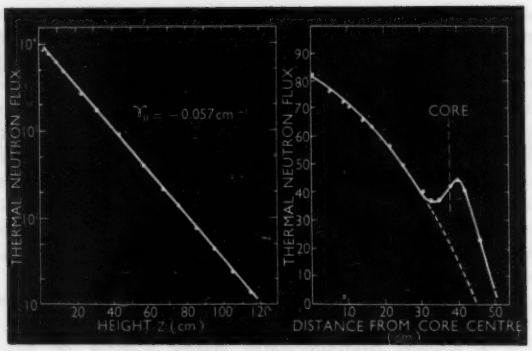


Fig. 3.—Characteristic curves obtained from exponential experiments showing the spatial distribution of the neutron flux in both the vertical and radial directions. The dotted curve indicates the calculated flux when using the equations shown below with the extrapolated core dimensions.

In addition to these flux measuring devices portable and fixed radiation monitors are provided for health monitoring. A β-γ probe and ratemeter gives visual and aural warnings when the radiation level on the platform exceeds one third the maximum permissible level. Portable monitors are used for surveying the β-γ, slow and fast neutron fluxes. Film badges and neutron plates are worn by all personnel entering the laboratory.

Preliminary Results

Fig. 3 shows a typical result obtained in an exponential experiment when the axial thermal neutron flux is measured with a BF_3 counter. In this example 256 fuel elements were used in a square lattice of 4.60 cm pitch (V_m/V_u= 1.73). An approximate theoretical expression for the flux ϕ is given by:

$$\phi = A \cos \frac{\pi x}{a} \cos \frac{\pi y}{a} \exp(-\gamma_{11} z)$$

where a is the extrapolated dimension of the sides and x, y and z are the co-ordinates with respect to the centre point of the base of the core.

The Laplacian or buckling of the core (K^2) is given by

$$K^2 = 2\left(\frac{\pi}{a}\right)^2 - \gamma_{11}^2 = \frac{K_\infty - 1}{M^2}$$

where K_∞ is the infinite multiplication constant and M the migration area of the lattice.

Assuming an extrapolation length of 7.5 cm (infinitely reflected system) and a migration area of 39 cm^2,

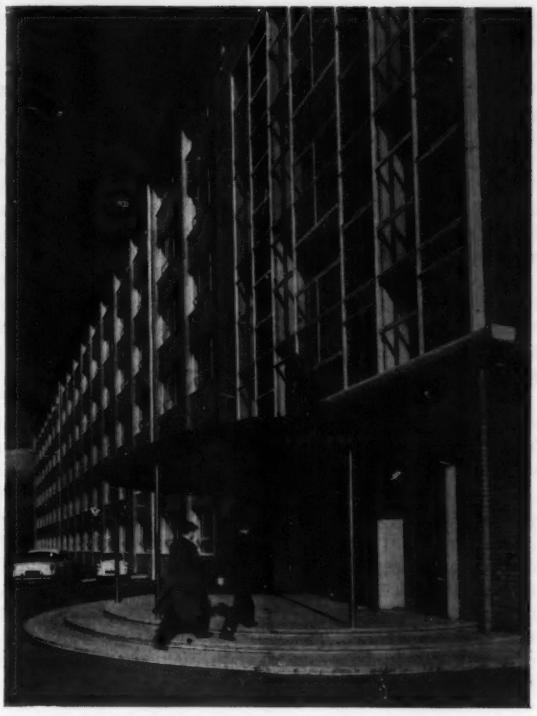
K^2 is found to be -8.0×10^{-4} cm^{-2},

whence

$$K_\infty = 0.97, \quad K_{eff} = 0.85_4$$

and the neutron multiplication of the system=7. Fig. 3 shows the horizontal flux distribution as obtained with the indium foil stringers, from which the extrapolation length is determined.

The experiments performed by the postgraduate course students have proved very valuable in bringing out the physical significance, and indeed the limitations of their reactor theory. Two postgraduate research students are working on the assembly, one is investigating the possibilities of pulsed-neutron techniques for buckling measurements and the other the measurement of neutron spectrum within the core.



The front entrance of A block of the former Industrial Group Headquarters at Risley, now the Production Group's H.Q.

Select Committee's Fifth Report On Estimates

The Select Committee finds that the Industrial Group has carried out its tasks with efficiency and success. Certain specific changes are recommended, particularly with regard to estimates and the use of industrial development capacity.

OVER the first half of this year a select committee of 36 Members of Parliament examined the activities and spending of the Industrial Group of the U.K. AEA; it has now published its report (H.M.S.O., 316, price 5s.). Due notice is taken of the splitting of the Group into Production on the one hand and Development and Engineering on the other, and the comments and recommendations made, remain applicable. In its conclusions the committee wished to record as its main impression . . . "that the Industrial Group has carried out its tasks with efficiency and success. This could easily have been otherwise in an organization which has been forced to grow so rapidly and which, in most of its work, has been breaking new frontiers of knowledge and technology." The committee is . . . "in general satisfied in the way that the Group has tackled a succession of novel problems and the cost consciousness shown in the development of a modern system for controlling expenditure."

Status of the Group

Treasury sanction is required by the AEA for each capital scheme and extra-mural research and development contract estimated to cost more than £100,000 and for certain less costly projects. It is the responsibility of the London office to exercise central management, co-ordinating policies of finance, administration and security, and the like. Relations with industry and co-ordination of certain aspects of technical policy are also within its domain, as well as the purchase of uranium and other special materials. The broad programme of work of the Industrial Group is submitted annually to the Authority for approval, R and D effort requiring the approval of the Member for Scientific Research through the Authority's research policy committee. Detailed interpretation of the programmes and implementation of the policies are the responsibility of the Industrial Group, and a wide measure of financial autonomy is allowed. It has power to initiate capital and research and development projects up to a value of £50,000 without reference to London office; 80% of the Group's projects exceed the £100,000 mark and therefore require direct Treasury sanction.

Industrial Group's Expenditure

Annual gross expenditure of the Group is estimated to have increased by 50% between '56/57 and '59/60 whilst net expenditure has increased by only 4% over the same period due to increased receipts. The net sum for '59/60 compared with the grant allocated in '58/59 is estimated to fall by about 16% although gross expenditure is expected to increase by 10%. These figures do not include raw material buying nor sales of military material.

The *annual capital* expenditure reached a peak in '57/58 with a total of £40 million. It is estimated to be £23 million in '59/60 rising again to £30 million in '60/61, at which point it is expected to level off. Initially the bulk of expenditure was for military installations, Calder Hall, for example, cost £33 million, but as these became complete so the emphasis has changed more and more to the civilian programme, through the medium of support functions such as fuel element production and processing, and research and development facilities. Capital expenditure on fuel element handling is expected to double between '58/59 and '60/61 and treble on R and D work.

The acceptance of the Fleck committee's recommendations resulted in a significant movement of technical effort to the factories and not only was a major general increase in the staff required but modifications were also necessary

to plant in existence, resulting in an increase of £4 million in capital cost.

Total capital value for reactor work is about £25 million being spent at about £2 million per year. The AGR prototype, started in the autumn of 1958 and due to be completed in the middle of 1961, is estimated to cost £8 million. On the production side, heavy capital expenditure was required in the setting up of the fuel element production factory at Springfields; the estimate made in 1955 was £30 million. To balance this, receipts from the sale of fuel elements in '58/59 were estimated at just under £1 million (mainly for experimental reactors) and they are expected to go up to £10 million in '59/60, £17 million in '60/61 and may reach £40 million a year in five or six years' time.

By '60/61 annual capital expenditure on R and D facilities including prototype reactors will be the largest single block and that on civil production, second, leaving military expenditure last.

Over the period '55/56 to '59/60 operating expenditure at the works is expected to have increased by 150%, and R and D revenue costs by 280% between '56/57 and '59/60. The operating rise results from the increasing military output but R and D is largely in support of reactor development and operation.

Staff Growth

The increases are reflected in the growth of staff employed by the Industrial Group. When the production division of the Ministry of Supply (later the Industrial Group) was formed in 1946, the total staff was 16, but by 1955 the number had risen to 10,000, and by March, 1959, to over 18,000. By '61/62 the figure is expected to exceed 23,000. At present more than half are employed in the factories; works staff increased by 16% between 1958 and 1959 and a further rise of 12% in the numbers is expected in the next year. The R and D branch increased by 9% between 1957 and 1958, whilst the 1960 total is expected to show a further increase of 22%, making an overall growth of 250% in five years when Dounreay is also included.

Under the new organization, which the committee welcomed as it should lead to more efficient administration and allow the Production Group to concentrate on their main objectives of reducing production costs, this Group will require to maintain a headquarters staff at Risley of only 300. The Development and Engineering Group strength, then, will, however, be in the region of 3,000.

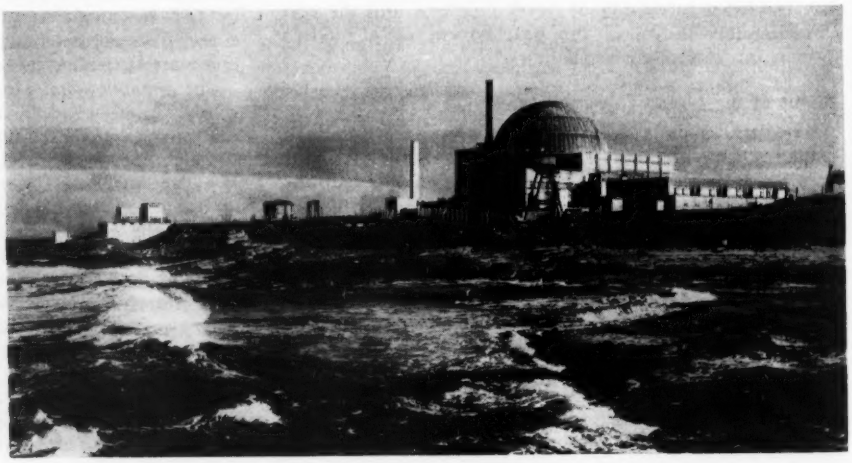
The committee has further comments to make on organization. The original arrangement of maintaining production research staff at the various works under the control of the R and D branch is criticized and the recommendation made that works general managers should not merely have power to call on R and D effort but should, in addition, have under their direct control a proper R and D section. The converse policy adopted at Dounreay is approved whereby the whole of the establishment, both operation and research, is under the control of one director co-ordinated by the D and E Group. Transfer of relevant research responsibilities to the works general managers was begun in July, 1959, in the reorganization of the Industrial Group.

Co-ordinating the efforts of the new Groups will not be easy as certain overlapping of responsibilities is inevitable. The committee feels that perhaps more formal arrangements for co-ordination and co-operation should be considered by the Authority and certainly that the whole question be regularly reviewed. Similarly, the committee is concerned at the number of separate research and development organizations within the Authority and the difficulty of co-ordinating the work. It recommends that interchange of staff between the various sections should be encouraged and emphasizes that a proper career structure should be established throughout the Authority based on an overall, rather than a parochial, system.

Expenditure Control

General approval is expressed at the control of expenditure and the cost consciousness shown by all sections of staff. The accounting adviser to the Authority went so far in evidence as to say that whereas he'd been obliged in the past to comment most critically on some sectors of public finance, he felt that the Industrial Group had done " extremely well."

Criticism is made, however, on the method of preparing budgets and the length of time that this takes, involving a great deal of labour and necessarily being somewhat tentative in view of the number of months prior to the final draft that the original estimate is made. The committee feels also that insufficient attention has been paid to the long-term financial implications of immediate projects both in terms of prototype construction and ancillary plant. It is pointed out that capital expenditure on a prototype

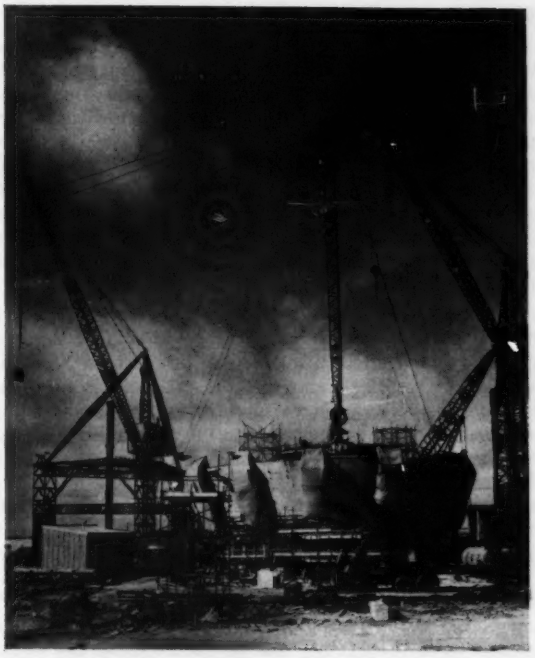


The fast breeder research reactor at Dounreay which is due to go critical soon.

fast reactor planned for construction in '63/67 will have resulted from a decision taken in 1953. Similarly, the decision to go ahead with the civil Magnox reactors resulted in the requirement for the new processing plant at Windscale which is estimated to cost £8 million. Proposals are at present under discussion for forecasting estimates to the Treasury for five years instead of three years as with the present system.

At the same time, tighter control is required on the estimation of projects and capital expenditure. The example is quoted of £33 million being voted for the Chapelcross reactors even before the site was chosen; the subsequent claim that the Authority had saved £3 million (which was due to good site conditions) is considered misleading. The necessity for rush sanctioning of capital expenditure is much less now that the military programme is largely satisfied.

The Group is to be congratulated on the accuracy of many of its estimates where experience has been obtained (Calder B reactors were within 1% of the original estimate) but the Springfields extension ran into development troubles and the Dounreay projects have cost considerably more than was anticipated; working in the north of Scotland is estimated to cost an additional £1 million. The present estimate for Dounreay is 38% higher than the original and it is believed that inadequate control of expenditure resulted in a drift wastage of £500,000. Steps have been taken to see there is no recurrence of this.



The advanced gas-cooled reactor (AGR) under construction at Windscale.

The Group's Income

It is the Authority's policy that as far as possible the cost of the work of the Industrial Group should be recovered from sales and other receipts. Expenditure on fundamental research, including that at Dounreay, is treated as a charge on the Exchequer. Receipts come from sale of fuel elements, sale of electricity generated at Calder Hall and Chapelcross, sale of limited quantities of various special chemicals, metals and also resale of graphite manufactured for the AEA under contract. In addition to these there are the receipts from the sale of commercially valuable information mainly in the form of royalty payments on whole reactor systems. These are based on the size of station built and the rate is about 10% of the value of the nuclear part of the station or approximately £5/kW installed. Receipts from Hinkley Point and Trawsfynydd will therefore be about £2.5 million each. Sale of electricity is estimated to realize nearly £4 million in '59/60 and resale of graphite £7 million.

The committee approves the principle of sharing with the Generating Board the financial risk associated with the burn-up of the Magnox elements. The Authority is not prepared to make full guarantees and the Generating Board is conversely not prepared to accept fuel without reasonable assurances. The committee warns the Authority on the dangers of chasing receipts too hard, by raising royalties or driving too hard a bargain on payments for the use of information as these would both hold back the country's nuclear development. In answer to complaints made by the consortia over the meagre fuel guarantees that the Authority was prepared to make for reactors sold abroad, the committee does no more than sympathize and classify the whole question as outside its terms of reference.

After analysing the ratio of competitive to non-competitive contracts placed by the Authority (in '58/59 81% were competitive if the big graphite contracts are excluded), the committee concludes that greater advantage could be taken of industrial interest and industrial facilities and competition. It recommends that both the number and the value of contracts for which competition is dispensed with, should steadily decline.

Production Costs

On reducing fuel element production costs, the committee emphasizes the importance of standardization and the minimization of the number of reactor types which this country is prepared to develop on a large scale. Of the total cost of Calder type fuel elements in '58/59, 70% represented the cost of the contained uranium and 30% works conversion cost. For the first civil stations, fuel elements are expected to be around £20,000 per ton, of which the uranium itself counts for £11,500. Production of plutonium rose by 76.5% between '55/56 and '58/59 whilst cost per unit fell by 35%. Cost of the fuel elements, irradiation and chemical processing contribute almost equally to the final figure.

Modifications to the production processes at Springfields have resulted in savings of about £300,000 per annum and modifications to purification processes can save £100,000 per annum. Also as a result of development work, the capital cost of the new primary separation plant will be £1 million cheaper than it would otherwise have been, and processing costs are down several hundred thousand pounds a year. Greater efficiency has also increased the output at Windscale, which has probably saved about £2 million capital cost for a new plant. Similarly at Capenhurst, the unit cost of production of enriched uranium hexafluoride has also decreased, coming down by 20% in the past three years.

The importance of continued research and development into these production processes is emphasized and the direct bearing on electricity generation costs that improved systems can bring. Between 15 and 20% of the effort of the R and D branch has been in support of the production processes, and this is deemed a very valuable investment.

The AEA fuel fabrication plant at Springfields.

Reactor Developments

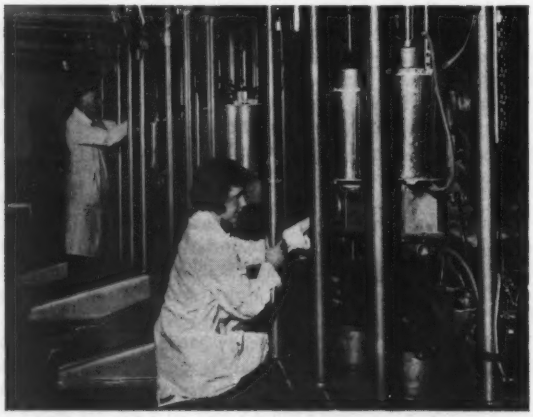
The development of reactor systems is next examined with particular reference to the estimated generating costs and the changes in costs of conventional generation. The committee concludes that the operation of nuclear power stations now, even if at present uneconomical, is essential for the achievement of really cheap nuclear power in the 1970s, and even if the need for cheap electricity has less immediate relevance than in 1955 the essential justification, based on the need to provide an additional source of energy to meet the growing demand for electricity, still stands.

The conclusion is drawn that it is absolutely imperative that the bulk of the Authority's effort should be devoted to the development of a low capital cost reactor for construction in the 1970s and that the fast reactor be given the highest priority. The wisdom of even diverting effort onto the SCHW is questioned, and the point reiterated that the minimum of reactor systems should be investigated. The committee welcomes the assurances of the Authority that the tempo of the work on the DFR is increasing and that the effort being devoted at Dounreay was near the maximum that the project could at present accommodate.

Due consideration is given to the consortia's views that effort should be devoted to the development of a small reactor for export; the Authority has at present no such projects on its programme and the committee on the whole supports this neglect.

Surprise is expressed at the rising level of research expenditure on the current Magnox stations, which is expected to go on up until 1961 and not to fall off again until 1964. This is partly due to the necessity for providing post-operation facilities, such as the £1 million element examination caves at Windscale. The committee feels nonetheless that this was diverting attention from the main theme of the Industrial Group, viz. the development of new systems, and that much of the work could be handled by the Generating Board's new laboratories at Berkeley and the consortia. The recommendation is made that only where facilities do not exist in these organizations should research on current reactors be handled by the Authority.

The committee feels that generally the Authority should now take more advantage of the skills and facilities of industry and that industry should be brought into closer partnership at all stages of reactor development. This would ensure that the nation's nuclear engineering skill was fully exploited, and that industry's resources were more effectively loaded; the result should be a speeding-up in the programme and an economy in public expenditure. Whilst approving the many channels of co-operation between industry and the Authority, industry should be made privy, at an earlier stage, to Authority thinking and development and given greater responsibilities in the development and design stages. At the same time, it would appear that industry has not responded as it might to opportunities to attach staff and the Authority criticized, in evidence, both the number and quality attached to the design office of the AGR. Nonetheless, the committee states that the Authority could do much more to give industry early practical experience and to undertake development under a research and development contract basis. The consortia would welcome this and would be prepared in many instances to contribute financially towards such projects. There are already moves to increase the number of development contracts put out, an example being that extra-mural research expenditure by Dounreay should increase tenfold between '58/59 and '59/60.



A battery of creep testing machines at the Culcheth Research Laboratories.

The Authority is against the development of whole reactor systems by the consortia, maintaining that the time is not yet ripe. Even the consortia themselves are not unanimous in agreeing that individual group development would allow proper dissemination of information on experimental results and a wide enough experience of development techniques. With some reservations, the committee supports the current Authority view but feels that the policy should be regularly reviewed and reconsidered now with regard to the development of small reactors and marine propulsion units.

Concerning the industrial fabrication of fuel elements, the Authority is quoted as being open-minded on the question, whereas industry appears to be divided in its opinions. Sir Christopher Hinton, chairman of the CEGB, in evidence, stated quite specifically he would be unwilling to buy fuel elements from anyone other than the Authority or from the consortium which had designed and built the reactor concerned. The recommendation is still made that when the new canning lines at Springfields become fully employed in '62/63 the Authority, the Generating Boards and the consortia should jointly consider the possible advantages of further production lines being handled by industry.

Apart from the specific recommendations detailed in this summary, the committee made it quite clear that it had been impressed by the efficiency, drive and purpose shown in the Industrial Group and the implication is quite clear that many equivalent organizations outside atomic energy would show up badly in comparison.

Soviet Fast Reactor—BR 5

A U.K. AEA party consisting of Dr. R. Hurst, director Dounreay, Dr. D. S. Oliver also from Dounreay, Dr. R. D. Smith from Harwell, and Mr. R. R. Matthews from Risley recently visited the Russian 5MW fast reactor. The invitation for the visit was made to Sir John Cockcroft by Prof. Emelyanov of the Soviet Academy of Sciences in Geneva last year.

By **R. R. MATTHEWS,**
M.A., A.M.I.Mech.E., A.M.I.Chem.E.
(Chief Engineer, Fast and Experimental Reactor Design Office, D. & E. Group, U.K. AEA)

BEFORE describing the fast reactor, it is worth outlining the history of fast reactor development in the U.S.S.R. The first reactor, BR 1, was built in 1955 as a zero energy assembly fuelled with plutonium and used for investigating fast reactor physics. This reactor is still in operation. Following this the work was extended by building a second reactor, BR 2, in 1956, also fuelled with plutonium. This reactor could be operated at power up to 100 kW. It provided facilities for physics experiments and irradiation of materials in fast neutron fluxes up to 10^{14} neutrons/cm^2, sec, besides giving experience of operating a reactor above ambient temperature. Mercury was used for removing heat as at that time they had no experience of sodium systems.

BR 2 was later dismantled and various parts, such as shielding, used for construction of the BR 5 reactor, which was completed in the middle of last year. This has a maximum power of 5 MW(t), is fuelled by plutonium oxide and is sodium cooled with inlet and outlet temperatures of 375° C and 450° C. The main purpose of the reactor is to gain burn-up data on fuel elements, to obtain practical experience in the operation of radioactive sodium circuits, and to carry out irradiation testing of various materials. It was not considered necessary to obtain further data on breeding gain so the normal blanket of natural or depleted uranium was omitted. This considerably simplified the design.

Core Assembly

The core consists of 80 hexagonal fuel sub-assemblies surrounded by two rows of blanket sub-assemblies. Each fuel sub-assembly contains 19 stainless-steel clad pins filled with plutonium oxide pellets and sealed after charging with helium gas. The pins—separated by spiral wire spacers—are rigidly fixed to the top and bottom of the sub-assemblies. The latter are supported at the bottom by a tube-plate and packed with about .020-in. clearance between each in the sodium tube of approx. 14-in. diam. There is no top tube-plate and no positive lateral restraint is provided either at the centre or top. Sodium flows upward through the core from a single inlet at the bottom of the central sodium tube to a single outlet above the core.

Control of the reactor is effected by movement of a nickel reflector external to the central sodium tube. This reflector is divided into two cylinders and either or both can be used for effecting large changes of reactivity. Two rods operating in the outer cylinder provide sensitive adjustment for automatic regulation of the reactor. The reflector cylinders are supported by electro-magnets and emergency shut-down is obtained by immediate release of the magnets. The heat generated by the reflector is removed by air cooling, and at shut-down the air can be heated in order to prevent the sodium from freezing. BF_3 counters are used for measuring flux level when starting up the reactor and ion chambers when operating at power. The instruments are located in the surrounding water tank opposite the core centre.

Shielding

The main shielding surrounding the core consists of a water tank 20 in. thick to moderate the fast neutrons followed by a cast iron ring 16 in. thick, and the whole enclosed in a concrete cell of 43 in. average thickness. A graphite thermal column 120 in. long is attached to one of the sides of the reflector and a number of horizontal and vertical channels are provided which enable measurements to be carried out in varying neutron fluxes. The upper shield consists of a boron carbide plug, the two rotating steel plugs and a removable top plug made of layers of paraffin wax and iron. The lower shield consists of a water layer 8 in. deep which enables the cell under the reactor to be entered only at shut-down.

The reactor has an experimental sodium loop which can operate at temperatures up to 600°C and is cooled independently of the main circuit. This loop can be installed and removed remotely through the bottom of the reactor and inserted up through the centre of the core, thus enabling samples to be irradiated at the maximum core flux. At the time of the visit this loop had not been completed. In addition there are three fast flux air cooled vertical thimbles opposite the core centre inside the inner reflector, and four horizontal neutron beams of various energies are also available for experiments.

At inlet and outlet to the reactor the sodium system is split into two 4-in. circuits provided with isolating and non-return valves. Each circuit includes a sodium/NaK heat exchanger, a mechanical pump and cold trap. The pump is a vertical type with overhung shaft so that the gland and bearings operate in the gas space. The motor is totally enclosed in a leak-tight housing bolted to the pump casing, with the casing pressure maintained slightly higher than the system pressure, so that any leakage through the gland is inwards. Argon is used for the cover gas. Cooling of sodium in the cold trap is achieved by using toluene at 130°C, this in turn being cooled by steam. 18% Cr, 8% Ni, titanium stabilized stainless steel is used throughout and all welds are x-rayed. No secondary containment is provided for the sodium circuits to ensure that coolant loss will not occur, but joints forming the weakest part of the circuits are each protected by a casing clamped over the weld and fitted with a spark plug type leak detector. The whole of the primary system is enclosed within a concrete cell which can be viewed through a shielding window or by television. The reactor has no outer containment building.

One secondary circuit is air-cooled and the other generates steam, but only the former was in use during the visit. Each circuit again includes a mechanical pump and cold trap, but the coolant is NaK. Steam is generated at 230 p.s.i.g. in a double wall shell-and-tube type heat exchanger, this type of construction being used to prevent sodium and water coming into contact in the event of a leak. Mercury is used as the heat transfer medium in the interspace and the mercury level and pressure are monitored for indication of sodium or water leakage. All the secondary circuit equipment is contained inside a single compartment which we inspected, while the reactor was producing heat.

We also inspected the control room which was laid out in a conventional manner with a central control desk and panels of instruments for general information. The reactor was then operating at 1 MW with sodium inlet temperature about 200°C. While we were there the power level was adjusted from 1 MW to 900 kW and back again by using the automatic regulator. The power level trace gave a steady movement and no overshoots or instability were observed.

A dry critical assembly was first achieved in the reactor in June, 1958. Subsequently the circuits were filled and

tested with sodium and zero energy operation commenced in January, 1959. The maximum power reached so far is 2½ MW and experience showed the need for a lengthy period for testing and commissioning.

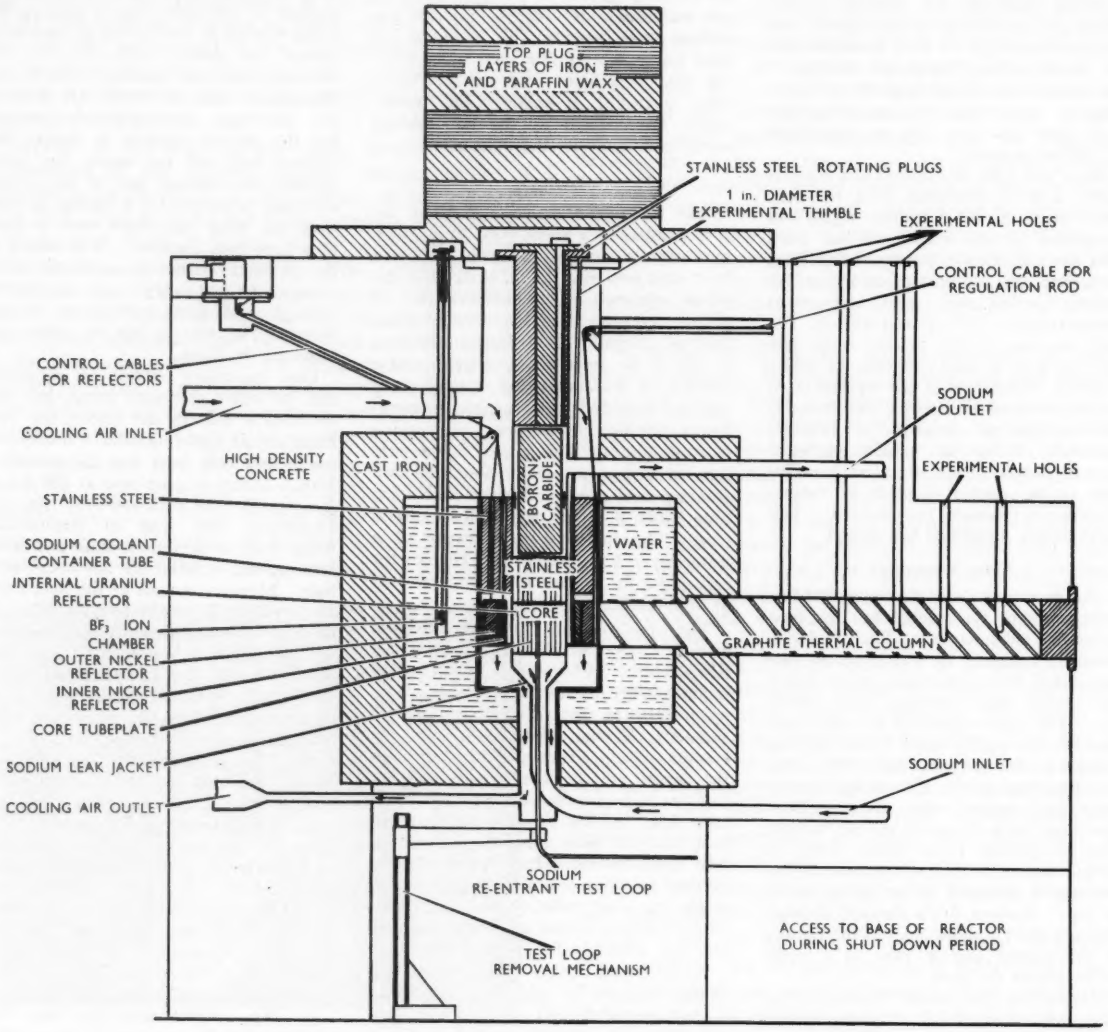
During the various discussions younger members of the fast reactor staff showed keen interest in the problems of building a large reactor and asked several questions about Dounreay. At Geneva last year it was stated that the U.S.S.R. was planning a 50 MW(E) station followed by one of 250 MW(E) and these seemed to have advanced as far as the design study stage. All concerned were firmly convinced that fast reactors would be successful but were quick to point out that with abundant supplies of fossil fuels Russia did not have the same incentive to develop reactor systems. An overall impression, however, was that the Russians were methodically following a programme of scientific development which would give the required information on physics and metallurgy for large fast reactors. On the engineering side the position was more obscure as the team did not see any parallel development in sodium technology and large scale components. The design of BR 5 is simple, with the quality of the workmanship in welding, valves and piping layout being comparable to U.K. standards.

The visit was valuable because it provided additional confirmation that it is possible to build and operate a fast reactor at power, and it was encouraging to learn that the reactor was very stable. The EBR I reactor in the U.S.A., with a maximum power of 1 MW(T), has been operating on U^{235} since 1951, and the Russian experience is now proving that plutonium can be used. While the team did not gain any novel ideas from the visit or learn of any new physics data, the discussions added confirmation to existing methods and constants for designing large fast reactor cores.

Basic Parameters of BR 50*

Electric power		50,000 kW
Diameter of core		65 cm
Height of core		65 cm
Thickness of core		60 cm
Average thermal flux in core		0.66×10^6 B.t.u./ft², h
Average specific heat generation		28 kW/ft³
Heat-transfer agent		sodium
Total flow rate of sodium		0.12×10^6 ft³/h
Average sodium flow rate in core		20 ft/sec
Average sodium output temperature		480°C
Steam temperature		415°C
Steam pressure		412 p.s.i.
Maximum neutron flux		9×10^{15} n/cm², sec
Breeding ratio		1.9
Core composition:		
heat-transfer agent	0.4	by volume
fuel elements	0.47	by volume
structural material	0.13	by volume

*Proc. 2nd Int. Conf., Vol. 9, P/2129



General arrangement of the U.S.S.R. fast reactor, BR 5. (This drawing is not to scale.)

GRAPHITE DATA *Contraction Predominant Effect*

THE intensive programme of study into graphite behaviour under irradiation is resulting in a progressive narrowing of the area of uncertainty. The present series of civilian stations were designed to accommodate a range of expansions and contractions but more precise data are now available and the later designs will be able to take full advantage. Some modifications will also be possible to the first reactors which have already been required to accept sleaving of the lower sections of the fuel channels to maintain a minimum graphite temperature of around 250°C.

Theoretically, and in the light of the limited irradiation data it was anticipated that in the direction parallel to extrusion the resulting deformation would lie between two curves, the upper of which showed a decreasing expansion with temperature, steadily approaching zero, and the lower a contraction progressively decreasing with increasing temperature to some constant value. The magnitude of the dimensional alteration can be stipulated simply in terms of ppm or proportion of length per integrated dose, most conveniently expressed as MWd/tonne of adjacent fuel. Using this expression, a simple curve against temperature is sufficient to define the phenomenon for a given grade of graphite, although for very high doses it is possible that the scale will contract.

It was generally assumed in the early days that the upper curve was the most probable, but more advanced theoretical treatment and detailed experimentation has proved the lower to be correct. At low temperatures, then, marked contraction takes place but as the temperature rises, so the contraction decreases, levelling off at a few hundred ppm per 1,000 MWd/t at temperatures corresponding to those met in the upper half of a power reactor.

The original predicted range of deformation in the direction perpendicular to extrusion, covered the area between two curves, the upper representing an expansion which decreased with temperature towards a constant value whilst the lower represented a contraction which also decreased with temperature but more slowly to a constant value. Here again experimental results have shown a marked divergence from the assumed "best curve." The upper curve is applicable at lower temperatures but the lower curve at higher; i.e., at the inlet end of a reactor the graphite expands but at the top end the graphite will contract. The flat portion of the curve implies a contraction of again a few hundred ppm per 1,000 MWd/t, and the cross-over point is at mid-reactor temperatures.

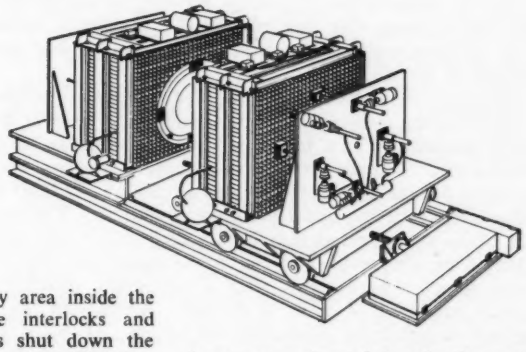
Insufficient evidence has yet been accumulated to show how these figures will change from one graphite to another but present indications are that the higher the graphitizing temperature the smaller the effect.

The dimensional changes affect not only the blocks in the graphite stack but also the lattice determinants—the tiles which are cut from the side faces of extruded blocks, the parallel dimension fixing the lattice spacing. The new data make it clear that, whereas it was assumed that the core would tend to expand slightly and require restraint, in practice the core blocks will contract within the rigid reflector and become loose. The maximum effect will be somewhat below pile centre where the flux is nearing maximum and the temperature is low. The integrated effect is not large, however; taking a central rating of 4 MW/tonne and the life of the reactor as 20 years the maximum contraction of an 8-in. tile will be about 0.065 in. This can be readily accommodated by proper design of blocks and tiles although some additional form of centring may be felt necessary to minimize channel distortion.

AETR Research

WITH the object of designing an economical, competitive nuclear power plant for the south-west region of the U.S., Atomics International have launched a programme, under contract with Southwest Atomic Energy Associates, for the design of an Advanced Epithermal Thorium Reactor (AETR). As the name implies the reactor will operate in the epithermal region on the thorium-uranium cycle and it is hoped that a conversion factor greater than unity can be achieved. To study the physics of the system a critical assembly has been built at A.I.'s field test area in Ventura County, Cal. The assembly, which is similar in general appearance to ZPR-3 Argonne's fast reactor facility, will be housed in a cell with 5 ft walls of concrete. The structure is of a square honeycomb type divided into two sections. One section is mounted on a fixed platform and the other on a movable carriage. The fuel is loaded in drawers which fit into the square metal tubes of the honeycomb structure. Loading is by hand but the reactor is brought to criticality by remote control.

Observations are made behind the shield in the control room, neutron detecting instruments being augmented by a remotely operated TV camera which can be focused on any area inside the shielded cell. Suitable interlocks and supervisory instruments shut down the reactor in the event of any malfunction.

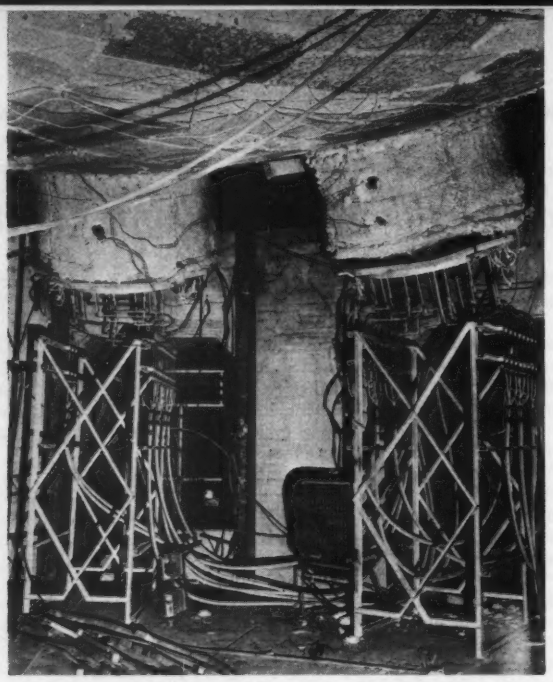


The advanced epithermal thorium critical assembly experiment.

To achieve criticality the assembly is built up, drawer by drawer, with the geometry required for the neutron balance previously predicted by computer codes. After a series of experiments have been conducted, they are compared with the analytical predictions so that the utility of a particular mathematical model can be assessed. With the AETR, not only are the usual mathematical descriptions of the reactor in doubt, but detailed information is lacking concerning the scattering, absorption, fission and leakage of neutrons in epithermal systems.

One of the difficulties in constructing a critical assembly which duplicates the AETR design is the lack of U^{233}. To overcome this the assembly design has been arranged so that only the central region of spherical assembly corresponds to the proposed AETR-type fuel mixtures. The central U^{233} fuel test region is surrounded by a buffer region containing U^{235} which is in turn surrounded by a thermal driver region. The use of this series of concentric shells reduces the amount of U^{233} necessary to obtain criticality while still preserving the nuclear characteristics of the central test region.

The critical assembly room which will house the reactor and related instruments is essentially a containment vault with seals on the doors and other openings. Large movable shield doors, a removable wall section, and a two-ton capacity crane in the room allow for access for bulky and heavy equipment.



For stress relieving more than 2 MW of heat was supplied to bring the temperature of the vessel up to 575-625°C.

First Berkeley Vessel Proved

The pressure vessel for No. 1 reactor at Berkeley has now been stress-relieved and pneumatically pressure tested. Maximum pressure during the test was 211 p.s.i.

THE first of the 150,000 cu ft Berkeley reactor vessels successfully completed its pressure testing on June 7. Apart from being the largest vessel of its kind (based on a volume × pressure assessment) the operation was noteworthy in that this was a pneumatic test which required considerable prior organization and one which passed off smoothly and showed that the local stresses set up in the vessel at design pressure at no point exceeded 50% of the yield stress.

On completion of the welding operations the first step was to stress relieve the vessel and this was completed at Easter. Basic requirement was to raise the temperature of the whole vessel to 575-625°C whilst ensuring that the maximum temperature differential between the highest and the lowest points was less than 50°C. Maximum allowable temperature for any part of the vessel was also defined at 650°C.

An array of stainless steel-sheathed magnesia-insulated radiant-heating elements was fitted around the walls of the vessel nominally 12 in. from the surface, the banks being divided into 24 zones for control purposes. Heaters were provided for the diagrid (which was already in position) to allow stress relieving under the same conditions. The outside of the vessel had already been lagged in 7 in. Caposite retained by pins welded to the vessel except for the top dome which was covered with a temporary insulation blanket consisting of 24 in. of Rocksil. Aluminium cleading will complete the permanent insulation. At this stage in the process the stand-pipe stubs were in position and the main duct stubs including the first circumferential weld beyond the vessel. Over 2 MW of heat was required to bring the vessel up to temperature at the rate shown in Fig. 1; great care was taken to eliminate the effects of draughts and double doors were fitted at all access points into the reactor vault.

The temperature was raised over a period of 69 hours to the specified temperatures, independent control of the zone heating ensuring that the maximum temperature differential was not exceeded. Thermocouples had previously been affixed to both the inside and the outside of the vessel, the inside ones being used for zone control and the outside ones for proving the temperature. Discrepancies at one time in the readings were found to be due to drift in the cold junction temperatures. The vessel was soaked at 600°C for a period of eight hours—twice the minimum time set by British Standards which calls for one hour per inch; the maximum thickness of steel in the vessel around the outlet duct is 4 in. Following this soaking period, the vessel was allowed to cool at a speed determined by the maximum temperature gradient down to 300°C. The gradual cooling process was continued after this point although British Standards procedure does not insist on this.

Following the stress relief operation all the welds in the vessel and the diagrid were examined by the magnetic crack detection method. This examination revealed the presence of a small number of minor cracks in fillet welds, these were removed by grinding before the pressure test took place.

Before the pressure vessel could be tested a considerable amount of preparatory work was necessary. Equipment used in the stress relieving operation was removed and all openings into the vessel were closed with blanks capable of withstanding the test pressure. Initially the seals were made with rubber rings under compression but these were found to be unsatisfactory and were replaced by Klingerite packing. The site supply of compressed air capable of giving 90-100 p.s.i. was augmented by a booster allowing a proportion to be compressed to 211 p.s.i. but in addition four Ingersoll Rand compressors were installed immediately outside the biological shield. These compressors were fitted with after coolers which allowed the temperature of the injected air to be controlled.

A major consideration in an operation of this magnitude when using pneumatic rather than hydraulic testing is the safety of the operators and the surrounding area. Both the Factory Inspectorate and the Home Office were consulted

Interior of the Berkeley pressure vessel.

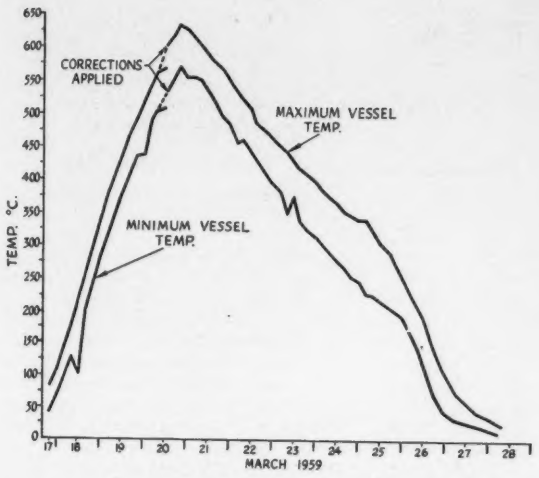


Fig. 1.—Stress relieving of No. 1 reactor vessel was spread over 11 days in March this year.

and, whilst at one time it was thought that the camp site might need to be evacuated, the conclusion was drawn that due to the height of the concrete wall which extends some 50 ft or more above the biological shield, this was unnecessary. A radius of 400 ft was finally decided as the maximum danger area to be cleared around the vessel.

To ensure complete control of movements within the site area additional security reinforcements were employed and, during the significant time, access to the site was only possible through the main gate which was in radio communication with the supervisory committee. Transit of personnel was only permitted following a reduction in pressure.

To check the stresses in the vessel some 400 electric resistance strain gauges were fixed with Araldite to the wall, half of them inside and half outside, at positions selected by A.E.I.-John Thompson and Lloyds. They were concentrated around the area of anticipated maximum stress, viz., around the branches and the feet; it was felt unnecessary to install them around the barrel itself. Plumbers' resin was also spread in 550 places over the welds and around the critical areas, to allow visual inspection for any yielding. Lloyds were responsible for the strain gauge readings and also for their immediate interpretation. John Thompsons exercised executive control over the pressure testing operation and a central committee comprising A.E.I.-J.T., the CEGB, Lloyds and the AEA was established to give on the spot decisions should the need arise.

To eliminate the danger of brittle fracture failure, the whole vessel was raised to a temperature of greater than 75°F. The vault was blanked off and heaters were provided outside and (initially) within the vessel before the testing. When the vessel had attained an average temperature of 85-90°F the inside heaters were removed and the pressure vessel was maintained at the required temperature by the external heaters and by controlling the after coolers on the compressors.

Prior to the main test the vessel was brought up to 70 p.s.i. to check the blanks. Certain leaks were detected and the packing modifications were made at this stage. After further checking of the blanks the vessel was again brought up to 70 p.s.i. on the night of Friday, June 5 and maintained at this pressure until the general works exit at Saturday lunch time. At this point, the site was sealed off and the team of 60 inspectors assembled within the reactor

Inside the top dome of the pressure vessel before pressure testing; the white bands are the internal strain gauges coverings.

building in a prepared room on the first floor outside the biological shield. The vessel was then progressively brought up to predetermined pressures (see Fig. 2) where the strain gauges were read, the pressure was then reduced by 15 p.s.i. at which point a visual inspection was made of the plumbers' resin. The maximum pressure reached was 211 p.s.i., 50% in excess of the design pressure with a corrosion allowance corresponding to 1/16 in. Operational pressure will be 125 p.s.i.g. and the design pressure was 137½ p.s.i.g. Average design stress was 9.4 tons/in.² and the highest local stresses found at a small number of points were in the region 13-14 tons/in.². These figures should be compared with a material yield stress of 18 tons/in.²

In addition to the main pressure test, readings were also taken of bending stresses when moments of up to 209.6 tons/ft were applied to the inlet and outlet ducts and measurements were also made of the tilts of the stand-pipe bosses. These figures were required by the design staff for checking the calculated figures.

Only one hitch occurred in the test when a leak in the blank of one of the 6 in. branches was discovered. Manipulation, however, cured this during the next inspection period. During the depressurizing stage a comprehensive leak testing programme was also instituted in which all fillet welds were painted with Tepol and visually inspected; no leaks were found.

Work on the vessel is now nearing its final stages prior to the loading of the graphite. The entire internal surface has been shot blasted and painted with Blast-Seel. The original temporary structure within the vessel has been replaced with shot-blasted and Blast-Seeled scaffolding and work on the inner skin and cooling manifolds is nearing completion. Graphite laying should commence in October.

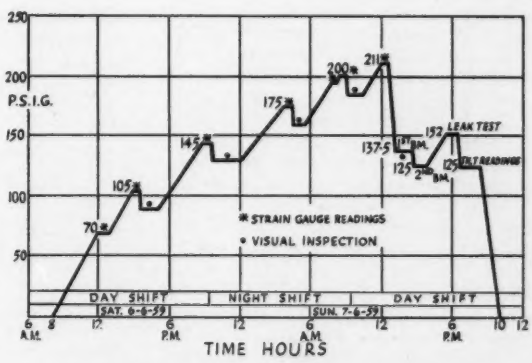


Fig. 2.—Time/pressure curve for the pressure test.

Research Reports

AERE Report No: M/M219

Part I: The Possible Effects of Irradiation in a Nuclear Reactor on the Properties of Steel - - - - - - - by S. F. Pugh

Part II: A Programme for Investigating Neutron Irradiation Effects in Iron and Steels - . - - by D. R. Harries and C. Judge

THE investigation, initiated in 1955 and still proceeding, concerns the changes caused by neutron radiation in the mechanical properties of steels, employed as constructional materials in uranium-fuelled reactors. At the inception of the testing programme little was known on the subject beyond certain observations on the loss of ductility in carbon steels so used and, consequently, the main emphasis in this study was placed on the exploration of the rise of the ductile-brittle transition temperature in welded steels of various compositions and plate thicknesses. This aspect of the work is still of major importance in the present phase of the investigation, but, as the information becoming available on the various aspects of the problems grows, the scope of the work covered expands and now embraces notched-bar and tensile tests on numerous steels, as well as studies of the effects of both irradiation and metallurgical variables on the susceptibility of steels to radiation damage.

The test objects are specimens of welded plate from commercial steels and specimens (not welded) of "standard" mild steel plate. The former are representative of the steels used in Calder Hall pressure vessels (Lowtem, Hitem, a silicon-killed mild steel and a low-alloy steel of 1% Cr and 0.5% Mo content) and steels used in pressure vessels of water-cooled reactors (Ducol W.30 and a 3% Ni steel). The standard mild steel has a composition of (A) 0.24% C, 0.15% Si, 0.55% Mn, and (B) 0.13% C, 0.16% Si, 1.49% Mn. Due to a higher manganese: carbon ratio, "B" has a lower transition temperature (−85°C) in the unirradiated condition than "A" (−10°C).

The present status of the irradiation programme on commercial steels is shown in a table. A total of 2,830 specimens is involved. Details of welding conditions and heat treatment as well as an analysis of the world deposits are given. The effects of neutron irradiation on steels bear a qualitative resemblance to the changes on cold work and ageing. If proper correlations could be established, an out-of-pile test could be developed facilitating quantitative forecasts of irradiation behaviour. To this end, notched-bend samples of the commercial steels will be tested after strain ageing.

The specimens of the "A" and "B" mild steel plate are being tested in a series of experiments specified as follows: (a) The Effect of Integrated Neutron Flux. The object is to provide data re irradiation effects on the properties of steels with substantially different transition temperatures in the unirradiated condition. (b) The Effect of Irradiation Temperature. Evaluation of this temperature is important as the materials used in pressure vessels may be required to operate at temperatures in the vicinity of peaks known to exist in curves relating transition temperature to irradiation temperature. (c) The Effect of Neutron Flux Intensity. This series comprises accelerated irradiation tests designed to provide data for the assessment of the behaviour of components exposed to a low flux over a long period. (d) Recovery from Irradiation Damage. This study aims at recovering notch toughness and room temperature tensile properties by annealing processes carried out at selected temperatures. (e) The Effect of Metallurgical Structure of the Steel. The effect of grain size of the steel and the shape, size and distribution of the carbide particles on the susceptibility of the steel to "radiation embrittlement" are investigated.

A separate table shows the progress of the work on standard mild steel plate specimens of the "A" and "B" composition. Irradiation is carried in BEPO and DIDO, and the Windscale and Calder reactors, the period of irradiation extending up to 270 days. The integrated neutron flux varies from 5×10^{18} n/cm² to 9×10^{19} n/cm² and the irradiation temperatures from 20° to 300° C.

In addition to the major avenues of the test programme just mentioned, a number of subsidiary subjects are studied as a further aid to understanding the effects of irradiation damage in iron and steels.

Pure iron and two varieties of pure iron-carbon alloys (of 0.16% C and 0.89% C content respectively) are submitted to tests with the aim of developing materials showing substantially less deterioration in their mechanical properties than commercial steels, when exposed to neutron irradiation. Boron steels form another subject. Natural boron contains 18.8% B-10. The thermal neutron capture cross section of the latter is 4,020 barns. On capture, B-10 emits an alpha particle with Li-7 remaining. These "fragments" have a total kinetic energy of 2.8 MeV which will be dissipated locally, displacing a large number of atoms in the vicinity and causing swelling (helium). Other subsidiary subjects are the properties of vacuum-melted steels, the effects of irradiation on hydrogen embrittlement, and the quality variations of austenitic steels, in particular of the 25% Cr-20% Ni type, which has not been investigated methodically in that respect previously and is of interest in connection with the gas-cooled, heavy-water moderated type of reactors.

In the Report, the description of the test programme is preceded by a review on the basic phenomena and ideas currently known on the subject of radiation damage and, in particular, on the effects of neutron (fast and thermal) on the brittle fracture characteristics of mild steel. This review is highly informative, giving a complete picture of present-day knowledge in that field pointing at the same time at the gaps still to be filled and the considerations which govern the planning of the test.

Meetings

October 6.—The Institute of Marine Engineers (Memorial Building, 76 Mark Lane, E.C.3, 5.30 p.m.). Presidential address, Sir William Wallace.

October 6.—The Institution of Engineers and Shipbuilders in Scotland (39 Elmbank Crescent, Glasgow, 6.30 p.m.). Presidential address, J. Brown.

October 7.—The Joint Panel on Nuclear Marine Propulsion (The Institution of Naval Architects, 10 Upper Belgrave Street, S.W.1, 4.45 p.m.). "Nuclear-powered Dry Cargo Ships," E. C. B. Corlett and E. P. Hawthorne.

October 7.—The British Institute of Radio Engineers (London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, W.C.1, 6.30 p.m.). "Some Reflections on Computer Design," W. Renwick.

October 7.—The British Institute of Radio Engineers, South Western Section (School of Management Studies, Unity Street, Bristol, 6 p.m.). "The Drift of Electronics," Captain L. Hix.

October 9.—The Institution of Electrical Engineers (Savoy Place, W.C.2, 5.30 p.m.). Inaugural Address, Sir Willis Jackson.

October 14.—The British Institute of Radio Engineers (London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, W.C.1, 6.30 p.m.). Students Meeting. "The Use of Transistors in Communication and Control," E. Wolfendale.

October 14.—Bradwell Engineering Society (Staff Branch, 6.15 p.m.). "Electronic Digital Computers. What they do and how they do it," K. Nicol.

October 15.—Liverpool Metallurgical Society (The Library of the Department of Metallurgy, University of Liverpool, 7 p.m.). "The Production and Use of Steel Wire and Steel Wire Ropes," B. Ryan.

October 21.—The Institution of Mechanical Engineers, Steam Group (1 Birdcage Walk, S.W.1, 6 p.m.). "Present-day Feed-water Treatment for High-pressure Boilers," P. Hamer.

October 23.—West of Scotland Iron and Steel Institute (39 Elmbank Crescent, Glasgow, 6.45 p.m.). Presidential address, J. W. Todd.

October 28.—The Institution of Mechanical Engineers, Applied Mechanics Group (1 Birdcage Walk, S.W.1, 6 p.m.). "Strength of Thick Cylinders Subjected to Repeated Internal Pressure," Professor J. L. Morrison, Professor B. Crossland and J. S. C. Parry.

Construction is under way on the Beloyarsk nuclear power station in the Ural Mountains in the U.S.S.R. The two reactors, with a total capacity of 200 MW, will be graphite moderated using slightly enriched uranium with water cooling. The plant is expected to go critical in 1961.

World News

International

THE OEEC CONVENTION on the establishment of security control in nuclear energy has now come into force. It is designed mainly to ensure that joint nuclear facilities developed with the help of the organization are used exclusively for peaceful purposes. The Convention was signed in December, 1957, and has now been ratified by all member countries.

THE EXPORT-IMPORT BANK of Washington have signed agreements with Euratom implementing the $135 million credit for assisting in the construction of nuclear plants under the U.S.-Euratom agreement. Total cost of the programme is expected to be about $350 million.

A HIGH ENERGY particle accelerator conference was held at the CERN headquarters during September.

FIVE-DAY international conference on the applications of large radiation sources was held by the IAEA in Warsaw during September.

United Kingdom

DRAFT REGULATIONS are being studied by the Ministry of Transport, in consultation with the AEA, to safeguard the carrying of radioactive materials by road. At the moment no statutory regulation governing the transport by road of such materials exist. (A container carrying radioactive isotopes was lost from a lorry recently but was soon recovered.)

DELIVERIES OF FUEL have been completed for the Hawker Siddeley research reactor, JASON, which is expected to go critical shortly.

FIRST THREE of 90 European scientists who will participate in the OEEC project, DRAGON, at Winfrith, arrived on September 21 to take up their appointments. Dr. C. Hintermann, who is to be the deputy head of the research and development division, was among them.

A LABOUR DISPUTE has interrupted work at Chapelcross; 800 construction workers are demanding increases in pay for working in the active section of the site.

DURING THE CONFERENCE of the International Union of Marine Insurance, in London, it was disclosed that British underwriters are now insuring against nuclear damage to hulls and ordinary cargoes.

Cdr. B. E. P. Sambourne, designate captain of the *Dreadnought*, talking to members of the Press in the comfortable mess of the *Skipjack* during her recent visit to the U.K.

Australia

RESEARCH REACTOR, HIFAR, is to be used for irradiation tests on foodstuffs and plans to use radioactive isotopes in a full-scale test to aid Queensland's sugar industry have been announced.

Canada

RULES GOVERNING the supply of uranium to countries with which Canada has no bilateral agreement have been altered. Previously no single producer could supply more than 250 lb at a time to such non-agreement countries, the total sales being limited to 2,500 lb. It has now been decided to allow any part of the entire 2,500 lb to be supplied by one producer.

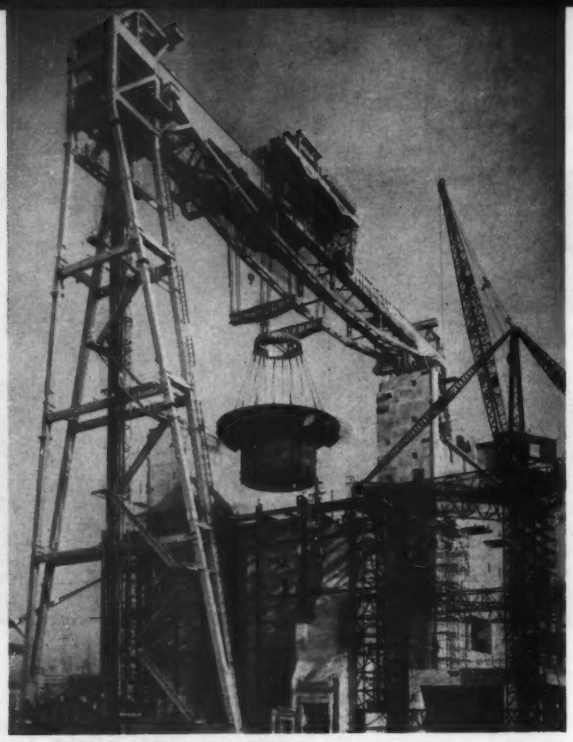
SITE FOR THE FIRST large nuclear power station—the 200 MW CANDU—will be at Kincardine on the shore of Lake Huron. The 2,300 acres for the $60 million station will have to be approved by the Atomic Energy Control Board. Atomic Energy of Canada are to build the plant.

Denmark

THREE FIRMS will assist in the construction of the Euratom Research Centre at Mol, Belgium. They are: Preben Hansen (architects), Steensen and Varming (civil engineers) and Mogens Balslev (electrical engineers). Denmark is not a member of Euratom.

Formosa

A RESEARCH REACTOR is to be installed at the Nuclear Research Institute of the National Tsinghua University by the end of the year.



The first section of the 67-ft diameter steel pressure vessel of the number one reactor at Hinkley Point being lifted into place by a Goliath crane.

France

REPAIRS to the 30-ft crack in the EDF-1 pressure vessel at Chinon are under way.

A LARGE NUCLEAR research centre is to be built at Cadarache in Southern France by the French Commissariat. To be constructed at an estimated cost of 20,000 million francs the research centre will be destined for investigating the improvement of existing types of reactors. Three reactors will be installed, PEGASUS, a swimming-pool type to investigate fuel elements for gas-cooled reactors, BRENDA for enriched uranium at high temperatures experiments and RHAPSODY, a fast neutron-type cooled by liquid sodium.

A SYMPOSIUM on the metallurgy of plutonium will be held in Grenoble from April 19 to 22, 1960, by the French Society for Metallurgy.

Germany

A FUEL AGREEMENT CONTRACT with the U.S. has been extended. A new clause allows a total of up to 8 kg of U^{235} per reactor, enriched up to 90%, to be bought or obtained on lease for use in research and material testing reactors.

India

SITE FOR THE FIRST nuclear power station will be somewhere between Ahmedabad and Bombay, it has been officially stated by the Atomic Energy Commission. The station will be able to supply power to Gujerat and Saurashtra.

Iraq

A RUSSIAN REACTOR for producing isotopes for medical purposes and scientific research is to be installed at the Atomic Energy Commission centre in Baghdad. This follows an agreement recently signed with the U.S.S.R. for technical assistance in developing nuclear energy. The number of Iraqi students, studying at Russian nuclear centres, is to be increased from 300 to 375.

Israel

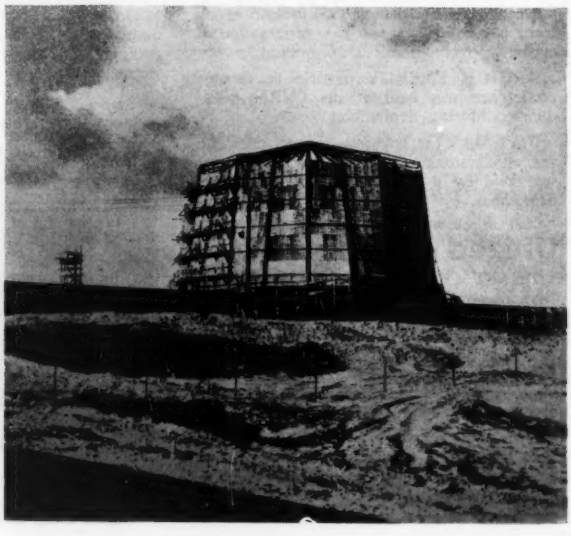
FIRST MASTER'S DEGREES in nuclear science will be granted by the Institute of Technology early in 1960 when four graduate students are due to complete nuclear research projects.

THE 1 MW REACTOR, now being built by AMF Atomics of the U.S. near Rishon le Zion, will be completed by the end of this year.

Italy

A NEW COMMITTEE to co-ordinate government action in nuclear energy has been announced in Parliament by the Minister for Government Investments.

WORK ON THE NEW nuclear centre at San Pero a Grado (near Pisa) has begun. The centre will house a Babcock and Wilcox 5 MW swimming-pool type research reactor which will incorporate three divisions of the swimming-pool by aluminium walls.



The 1-MW research reactor being built by AMF Atomics at Rishon le Zion, Israel. The reactor is expected to go critical at the end of the year.

Netherlands

AN ATOMIC ENERGY ACT is to be placed before Parliament providing for the setting up of an Atomic Council. The Government has also announced that it will increase financial contributions to the Netherlands Reactor Centre and also acquire a greater shareholding in the Centre.

North Korea

AN AGREEMENT for aid in developing nuclear energy has been signed with the U.S.S.R. Aid will be given in the building of a nuclear reactor, a laboratory of nuclear physics and an isotope laboratory.

Norway

OFFICIAL OPENING CEREMONY of the Halden reactor project will be performed by King Olav of Norway on October 10.

Peru

URANIUM ORE DEPOSITS with contents of between 5.8 and 9.2% have been discovered in the province of La Convencion in southern Peru. An accurate assessment of the quality and quantity has not yet been made but prospecting in the highlands is continuing.

Poland

THE STATE COUNCIL have approved plans for the establishment of a second research reactor. It will be hydrogen-cooled, graphite-moderated, with highly enriched uranium fuel. U.S.S.R. scientists have assisted in the design of the reactor.

Portugal

THE BUILDING of a pilot nuclear power plant of 30 to 50 MW to be started by 1965-67 and a prototype 150 MW power station by 1970-71 has been recommended by the Companhia Portuguesa de Industrias Nucleares. It is estimated that Portugal will have to install about 2,000 MW(E) between 1970-80 to meet growing demands.

South Africa

MINISTER OF MINES and chairman of the Atomic Energy Board, Senator J. de Klerk, has announced that it has been decided to purchase a 5 MW research reactor in the immediate future and to construct an advanced reactor at a later date. This follows Government approval of the £800,000 a year research programme for the AEB.

Switzerland

THE FEDERAL COUNCIL has asked the Federal Assembly to approve a credit of SF.4 million of which 1.2 million would be spent during 1960 as Switzerland's contribution towards the cost of the OEEC research project, DRAGON, at Winfrith, U.K.

U.S.S.R.

"LENIN" ON TRIAL RUN. The world's first nuclear-powered surface ship, the 16,000-ton ice-breaker "Lenin," sailed on September 16 on her first trial run in the Baltic. Powered by three pressurized light-water reactors the ship is capable of developing 44,000 h.p. "Lenin" is 440 ft long with a beam of 90 ft.

U.S.A.

CONTRACTS have been signed by the AEC with Philadelphia Electric and General Dynamics for the construction of a 40 MW prototype high-temperature, gas-cooled power station at Peach Bottom on the Susquehanna River near Pennsylvania. Total cost is expected to be $40 million.

A LONG RANGE PROGRAMME to develop effective thermal breeder reactors which will make full use of the latent energy in thorium has been initiated by the AEC. Oak Ridge will have the responsibility for the programme.

A $4.3 MILLION CONTRACT to design and engineer a new facility at their Hanford Works for the processing of commercial reactor fuels has been awarded Vitro Engineering by the AEC.

A STUDY PROPOSAL, for increasing the efficiency of nuclear power plants by superheating steam, by General Electric, has been selected by the AEC for contract negotiations. The proposal is valued at $2.7 million. The company have also designed and built a material test reactor to irradiate nuclear aircraft components and sub-systems at the U.S. Air Forces nuclear laboratory.

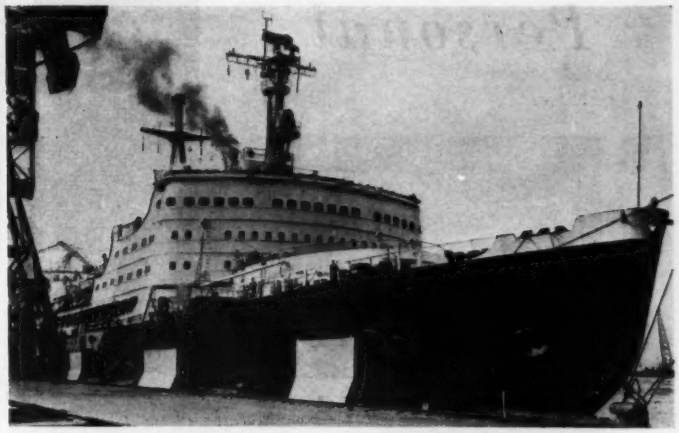
THE FINAL DESIGN of a sodium-to-sodium heat exchanger and a sodium-to-water steam generator contract has been awarded by the AEC to Alco Products.

A SMALL SIZE pressurized water reactor plant is one of the new proposals to be called for by the AEC.

THE THIRD CONFERENCE on analytical chemistry in nuclear reactor technology will be held at the Oak Ridge National Laboratory from October 26-29.

A TRIGA REACTOR, built by General Dynamics, will be installed at the new centre for nuclear technology at Cornell University. The reactor will have a steady state power level of 10 kW and will be capable of serving as a pulsed neutron source.

ATOMIC INDUSTRY EXHIBITIONS and symposia in San Francisco and Chicago are planned by the Atomic Industrial Forum in conjunction with the American Nuclear Society for Dec. 12-15, 1960 and early Nov., 1961 respectively.



Lenin, during recent mooring trials at Leningrad. The ship has an all-welded body and a speed of 18 knots.

A JOINT STUDY to explore the feasibility of a graphite-moderated, water-cooled, boiling and superheating reactor concept will be undertaken by Atomics International with Nuclear Power Group. The study is expected to cost $150,000.

PRELIMINARY DESIGNS for a $6 million facility for reprocessing nuclear reactor fuel elements have been started by General Electric. Under the planned AEC programme General Electric will reprocess from 50 to 150 tons a year of highly diversified low-enrichment spent fuel containing up to 5% U^{235}.

A SHIPMENT of almost 200,000 pounds of enriched uranium dioxide powder has been completed by Mallinckrodt Nuclear to Commonwealth Edison for DRESDEN.

A NATURAL CIRCULATION PWR is to be developed by General Electric for naval surface ships at KAPL, at a cost of $18.5 million.

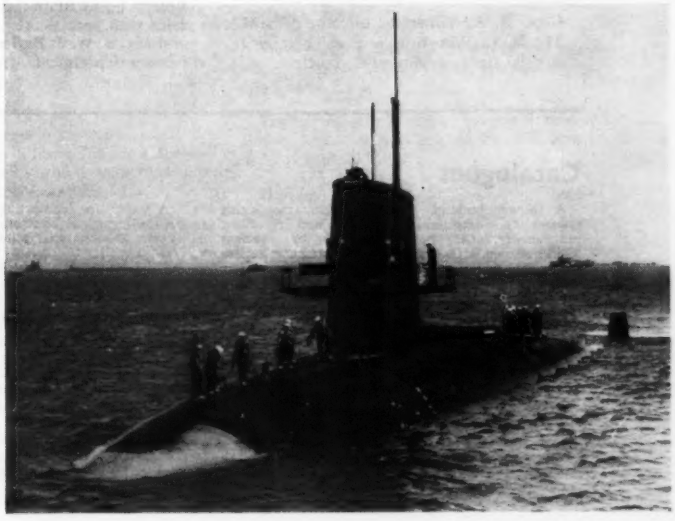
ONE-DAY SYMPOSIUM on the development and potential industrial uses of nuclear reactors for the production of low-temperature process steam will be held by the AEC at their Germantown headquarters on October 1.

A NUCLEAR TEST REACTOR (NTP) capable of testing reactor cores with power capacities up to 60 MW, as designed by Combustion Engineering, has been selected as a basis for contract negotiations by the AEC. Congress granted permission for the building of the reactor (estimated cost $5,000,000) in June.

A PARTED FUEL ELEMENT has been discovered at the sodium reactor experiment operated by Atomics International for the AEC at Santa Susana, Cal. No release of radioactive materials to the plant or environs occurred. Fuel elements are in the form of a cluster of seven stainless steel tubes, 6 ft long and ¾ in. in diameter containing uranium metal slugs.

UNIVERSITY OF BUFFALO is to be given permission by the AEC for the construction of a 1 MW pool-type reactor. The reactor will form part of a Nuclear Research Centre at the University.

CONTAINMENT STRUCTURE contract for the Piqua nuclear power plant has been awarded to Graver Tank and Manufacturing by Atomics International. The structure will be 123 ft high with an outside diameter of 73 ft.



Skipjack, the American nuclear-powered submarine of which *Dreadnought* will be almost an exact replica, during a recent visit to Portland.

Personal

Dr. L. M. Currie.

Mr. I. D. Carter.

Dr. R. G. Taecker.

Mr. R. G. Camp.

Appointments

Mr. G. C. Dale, a member of the health physics division, AERE, Aldermaston, as deputy physicist in the health and safety department of the CEGB.

Mr. R. E. Hollingsworth as deputy general manager of the U.S.AEC.

Dr. D. W. Ver Planck, as assistant director of the John Jay Hopkins Laboratory, Cal.

Dr. K. Fuchs as deputy director of the Central Institute for Atomic Physics in Leipzig, East Germany.

Dr. W. E. Frahn as Professor of Nuclear Physics at the University of Stellenbosch, South Africa.

Mr. H. L. Russo as manager in charge of the Selni project in the nuclear section of Westinghouse.

Dr. L. M. Currie as chairman of the 1960 Nuclear Congress Committee.

Prof. D. Williams as president of the Institution of Mining and Metallurgy.

Mr. I. D. Carter as commercial manager of Preformations.

Mr. F. S. Woodward as secretary of Consett Iron.

Mr. J. E. Robson to the board of Samuel Osborn.

Dr. R. G. Taecker as director of the International Institute of Nuclear Science and Engineering at the Argonne National Laboratory.

Mr. J. M. S. Coates to the board of George Angus.

Mr. I. Levin and **Mr. A. L. Wolley** to the boards of General Steel and Iron and G. R. Turner.

Mr. F. W. Stokes to the board of Powell Duffryn.

Capt. R. A. Villiers as director of SIMA.

Mr. R. C. Waugh as project engineer for industrial fuels of M. and C. Nuclear.

Mr. V. G. Burchill as assistant publicity manager and **Mr. R. Herbert** as chief Press officer of G.E.C.

Mr. D. H. Edson as group publicity manager and **Mr. G. O. Ham** as assistant of John Thompson. **Mr. L. Edgar,** formerly group publicity manager, continues in an advisory capacity.

Mr. G. H. Alder to the board of Amal, a subsidiary of I.C.I.

Mr. J. R. Bergne as assistant managing director of Ruston and Hornsby.

Mr. R. G. Camp as sales manager of Square D.

West German AEC appointments are: full members: **Prof. Dr. F. Strassmann, Prof. Dr. H. J. Born, Prof. Dr. W. Weizel, Dipl. Ing. P. Harke, Prof. Dr. W. Gentner** and **Prof. Dr. Th. Ernst.** Co-opted members are: **Prof. Dr. K. Wirtz** and **Prof. Dr. W. Groth.**

Mr. D. M. Checkley as president of Vitro Engineering.

A.E.I. appointments are: home district office executives: **Mr. W. A. Ankerson,** general manager; **Mr. R. S. D. Bagnall,** district office executive (Manchester); **Mr. K. G. Leach,** district office executive (Rugby). Regional managers: **Mr. L. Whitham,** Scottish; **Mr. A. C. Ellis,** north western; **Mr. A. J. Crawford,** northern; **Mr. W. J. Wilson,** north Midlands; **Mr. K. J. Clarke,** Midlands; **Mr. J. S. Hall,** south western; **Mr. E. Mead,** southern.

Mr. L. V. Moere to the board of Taylor Woodrow.

Lord Baillieu as President of BIM.

Mr. J. F. Herbert as general manager export sales of English Electric. **Mr. S. E. Bolton** as assistant general manager export sales with special interest in North America and **Mr. S. W. J. Butler** manager of overseas factory department.

Obituaries:

Nuclear Engineering regrets to announce the deaths of the following:—

Mr. A. B. Jones, Chief Administrative Officer of Winfrith, at the age of 58.

Mr. E. Philip Jenkins, a director of Robert Jenkins, on August 26.

Mr. H. S. Vance, a member of the U.S. AEC at the age of 69, on August 31.

Mr. W. J. Wood of Metropolitan Vickers, on September 5.

Resignations:

Mr. J. Dolphin, chief engineer at Harwell and Winfrith from the AEA.

Mr. R. W. Ladbrooke as a director of David Brown Construction Equipment.

Retirements:

Mr. W. J. Pool of British Thomson-Houston after 45 years' service.

Mr. C. W. Moller of Plessey after 40 years' service.

Mr. A. Hillier as chairman of Sperry Gyroscope.

An Appreciation:

With the death of **Mr. A. B. Jones** on August 12 the AEA has lost one of its foremost administrators. He was the first man to arrive at Harwell and it was he who took the "keys" from the R.A.F. on January 1, 1946. His drive and determination and ruthless (sometimes brusque) cutting of red tape were decisive factors in making Harwell a going concern so quickly. It was he who then began the opening up of Winfrith, and all on that site will regret that no longer is the solution to an administration problem—"ring up A.B."

Catalogues

A 16-page bulletin, M-59, describing monitoring systems for detecting, measuring and recording radioactivity, has been produced by **Nuclear Measurements.** (2460 Arlington Avenue, Indianapolis 18.)

The **U.S.AEC** has published a 75-page *Guide to Shipment of* U-235 *Enriched Uranium Materials*, which is obtainable from the Office of Technical Services, Department of Commerce, Washington 25, at $1.00 a copy.

The fifth edition of **Tracerlab's** *Radiochemical and Technical Services Catalogue*, listing reduced prices for all carbon 14 compounds has been produced. (1601 Trapelo Road, Waltham 54, Mass.)

A monthly publication of the **CERN** *Courier* is now available giving news of the organization's activities. (Geneva 23, Switzerland.)

A review of the new materials developed by **Alco** for nuclear engineering is included in their spring-summer edition of *Review*. (Schenectady 5, New York.)

A table for converting proton wavelengths to photon energy in electron volts has been published by the **Brookhaven National Laboratory.** (Upton, New York.)

Head Wrightson activities are reviewed in a new attractive brochure. (20 Buckingham Gate, London, S.W.1.)

A catalogue on courses in nuclear energy in **OEEC** countries for 1959-60 is now available. (2 rue Andre Pascal, Paris.)

An attractive publication, *Instrumentation for Atomic Energy*, has been produced by **Sunvic Controls.** (P.O. Box 1, Harlow, Essex.)

Siemens and Halske Components have produced a catalogue on their hall effect devices. (2 Caxton Street, London, S.W.1.)

TLD-8200, Nuclear Reactors, Built, Building or Planned in the U.S., is the name of a new **U.S. AEC** publication. (P.O. Box 62, Oak Ridge, Tennessee.)

Hilger and Watts give specifications of their autocollimators in a new catalogue. (98 St. Pancras Way, Camden Rd., London, N.W.1.)

The Wild Barfield heat-treatment journal Vol. VII No. 51 has a section on modern heat-treatment equipment. (7 Sigilian Avenue, London, W.C.1.)

Details of **Sound Diffusion's** new Datafonic system for remote and supervisory control are listed in a new brochure. (Duracraft Works, Portslade, Sussex.)

The Holmes Kemp dryers are described and illustrated in their publication No. 77. (Turnbridge, Huddersfield.)

John Thompson have produced brochures on nuclear fuel handling equipment, instrumentation and panels, ion exchange and pipework. (Ettingshall, Wolverhampton.)

A booklet called *Union Carbide Nuclear Graphite* gives a comprehensive description on nuclear graphite information. (30 East Forty-second Street, New York 17, N.Y.)

Industrial Notes

Ultra Electric have been commissioned by **British Thomson-Houston** to supply high-stability magnetic amplifiers, worth about £10,000, for the Berkeley power station. The amplifiers have been developed by the Special Products Division to form part of the reactor control system.

Whessoe have developed a special oxygen cutting machine to cut control apertures in the Bradwell reactor pressure vessel. The machine comprises two beams arranged to pivot at one end on a pintle located on the top dead centre of the spherical vessel. The outboard ends of the beams ride on a horizontal circular rail temporarily mounted on the body of the vessel with the cutting mechanism and burner on one beam and an optical device, to ensure precise location in marking out, on the other.

Eight **Pye** masterslave manipulators have been purchased by the Australian Government for the nuclear research centre near Sydney. **Pye** report that an experimental TV reactor camera has received a total neutron dose of the order of 10^{13} neutrons per square cm and has operated satisfactorily in fluxes in excess of 10^{12} neutrons per square cm per second for part of this period.

An isotope and fabrication-of-fuel-element exhibition will be held by the **AEA** in Sheffield from November 6 to 14.

Elliott Brothers are expected to take over the controlling interest of **A.E.I.** in **Isotope Developments** shortly.

William Boby have supplied an electrodialysis stack for experiments in decontamination of nuclear effluents to the Italian Comitato Nazionale per le Richerche Nucleari.

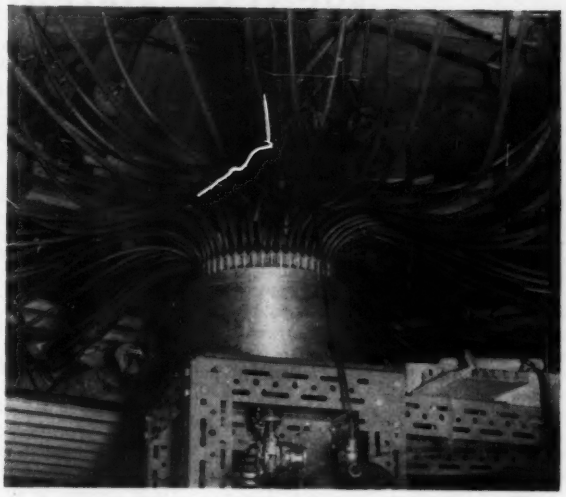
The Board of Trade are considering an application for the exemption from import duty of zirconium sponge.

Ekco Electronics are undertaking a sales promotion tour of Spain, France and Italy for nucleonic gauging equipment. The tour will end with an exhibition in Brussels staged by the Ekco representatives in Belgium, Physique Industrielle.

Honeywell Controls' American associates have developed a thermal plant simulator capable of duplicating the operating characteristics of virtually every type of nuclear power plant when linked to a reactor simulator.

A model Van de Graaff particle accelerator, costing £46 and capable of producing nearly half a million volts, has been developed by **W. B. Nicolson (Scientific Instruments).** The accelerator has been developed for college and school use and can be dismantled in a few minutes.

G.E.C. showed a film, "In the News," depicting the company's activities, at the Annual General Meeting on September 3.



A high-current switch developed by Hawker Siddeley Nuclear Power for the AEA capable of handling a 2,000,000 amp discharge. It is intended for controlled thermonuclear reaction projects.

South East London Technical College are to hold a course of six lectures as an introduction to nuclear physics for the engineer.

Two courses, lasting two years, on nuclear power will be conducted by the **Northampton College of Advanced Technology** in London. Course 1, An Introduction to Nuclear Power, begins on October 8 and the second, The Engineering Design of Nuclear Power Plant, on October 14.

The Bradwell Engineering Society are to stage a series of eight monthly lectures on nuclear engineering.

West Instruments, manufacturers of temperature control instruments, are to give courses of instruction on the saturable core reactor, commencing October 14 at the London office of the company.

Institute of Welding courses for October, at the School of Welding Technology, include one on pressure vessel and pipework (October 12-16).

The 1960 **Production Exhibition** will be held in the National Hall, Olympia, from April 25 to 30.

Midland Silicones have announced further price reductions for Silastic LS-53, a fluorinated silicone rubber which is serviceable from −60°C to over +200°C.

The 1960 **Mechanical Handling Exhibition** will be held at Earls Court from May 3 to 13.

Wolf Electric Tools have announced a maintenance service scheme for electric tool users.

Martonair have appointed **Ernest Lowe** of Johannesburg as agents for South Africa and the Central African Federation.

Nash and Thompson have concluded arrangements for the marketing of the G.K.N. micro-hardness tester, manufactured by **Associated Automation.**

Cory Brothers, a member of the Powell Duffryn Group, have acquired the share capital of **MacCleaster Chemical.**

Marconi Instruments offer a new high-grade, general-purpose oscilloscope, the TF 1330.

Powell Duffryn Carbon Products have introduced an additional range of graphite heat exchanger equipment, a condensing unit for handling corrosive vapours consisting of a graphite element or cartridge enclosed in a cylindrical steel jacket with carbon inlet and outlet heads. The unit is available in eight sizes from 4 ft² to 200 ft² H.T.A.

Recent changes of address are:—

British Insulated Callender's Cables' Northampton Depot is now at 18 St. George's Street. Tel: Northampton 1860.

E.M.B.'s Glasgow office is now at 17 Woodlands Road, Thornliebank. Tel: Giffnock 0188.

West's Piling and Construction's Scottish office is now at 181 West George Street, Glasgow.

English Electric's Bristol branch is now at Equity and Law Building, 36 Baldwin Street. Tel: Bristol 27304.

Dunlop are now at 23 King Street, London, S.W.1. Tel: WHI 3131.

Lancashire Dynamo's Newcastle office is now at Eagle Star House, 32 Mosley Street. Tel: Newcastle 28621.

D.P. Battery are now at 137 Victoria Street, London, S.W.1. Tel: MUS 1971.

The entire offices and works of **Birfield Engineering** have now been concentrated in part of the factory of Hardy Spicer at Chester Road, Erdington, Birmingham, 24, and the production and administration of **Birflo Controls** has been transferred to **Laycock Engineering,** Sheffield.

NEW BOOKS

The New Materials. By G. Leach. (Progress of Science Series: Editor, N. Calder.) 71 pp. Phoenix House, Ltd. (1958.) 9s. 6d.

"Do you realise that you are living in the most exciting century since the World began?" This introductory sentence to the first chapter sets the tone of the book. The author, a young scientist, obviously not required to concentrate on a particular discipline and free to rove through the broad realms of science, gives an account of the actualities and potentialities of the present scientific era, an account which unquestionably will enrapture the young and uninitiated to whom it is addressed. Although by layout the book is "confined" to a discussion of metals and plastics, in fact all specialized sciences and dominant technologies, such as the complex of atomic energy and vacuum techniques, are touched upon. Not all explanations given will be accepted by the specialist as exhaustive interpretations of current scientific definitions, but this book is conceived to serve as a pathfinder rather than a detailed source of information. In fact, special reference is made to books useful to readers who wish to study the various subjects more thoroughly.

In this age of specialization, this book of 71 pages, although intended in the first place for the boy still at school and undecided as to his career, may prove at the same time a refreshing piece of writing to the worker further advanced in professional life, when engaged in miscellaneous reading.

Using Steel Wisely. By L. Aitchison and W. I. Pumphrey. (241 pp. MacDonald & Evans, Ltd., 1958.) 44s.

The present volume is an offshoot from the same authors' excellent and more comprehensive work "Engineering Steels" and is essentially an essay on the principles underlying the selection of a suitable steel for any engineering application. This is a matter which was discussed in the previous volume, and the object of the present one is to make available the general ideas without a mass of detail on particular cases.

The book itself is divided into two parts. Part one entitled "Creating a Component" is of about 160 pages and deals in elementary terms with the metallurgy of casting, hot and cold working, heat treatment, surface treatment and shaping. Whilst the discussion is elementary it is never likely to be seriously misleading. Particular attention is paid to the possible sources of metallurgical defects which may damage an engineering component. In this part of the book a particularly valuable feature is the technical excellence of the carefully chosen photographs of microstructures and macrostructures, although the value of the latter to the engineering reader would be greatly increased if some indication of the scale of the reproduction were made available every time. It is to be hoped that the authors will arrange for this to be done in future editions.

In part two, which is entitled "Making the Best of It" and consists of about 70 pages, there is a general discussion of the quality of a steel and the significance of internal and external stress raisers as related to engineering factors of safety on the one hand, and the metallurgical considerations of part one on the other. Metallurgically speaking the treatment is sound and where the authors' private prejudices are stated, they appear in unambiguous terms and are in general justified.

H.J.A.

Analysis of Pipe Structures for Flexibility. By J. Gascoyne. (181 pp. Sir Isaac Pitman and Sons, Ltd., 1959.) 45s.

According to the Preface, the book is designed "to stimulate the interest of the student engineer and provide him with a foundation on which to build specialist knowledge." This is perhaps an underestimate of the value of the book, which would be of immediate practical use to a designer faced with the problem of producing a satisfactory pipe layout without overstressing the pipe materials.

After a brief introduction showing that very large stresses may easily be imposed on pipework by a rise in temperature, the author conducts the reader on a tour of the relevant sections of the British and American Codes of Practice dealing with pipe-stressing. Certain of these sections are reprinted as appendices in order that the book shall be self-contained and that the designer need not refer to other publications for essential information. Next, the author lists the various analytical methods of stressing pipework. One of these, the "Elastic-Centre" method, is then described in great detail. Worked examples are shown in full for pipe layouts in two and three dimensions. The work concludes with descriptive sections on pipe supports and flexible joints.

The concept of writing for a "student" has been carried to extremes which seem unjustifiable. For example, four pages of text are devoted to a description of the method used for obtaining hanger support loads. In the reviewer's opinion it would have been sufficient for the author to have specified that the loads might be obtained by taking moments, and moving the worked example by an appendix for the benefit of those students who need guidance on this process.

As a result of writing for the hypothetical student, many formulæ are presented without attempt at justification. The reviewer believes that even though the author might consider the derivation of many of the formulæ unnecessary in a compact work of this nature, references should have been made to sources of information in which the derivation of the formulæ might have been studied. This is particularly true of the sections covering the stresses in the pipework which are to be compared with the maximum permissible values stipulated by the Codes of Practice. Certain simplifications are made and it would be interesting to know whether these are based on experience or on theoretical grounds.

These criticisms are, of course, an attack on providing a book which teaches a method rather than teaching fundamental principles.

In spite of the criticisms the work will be found useful for many designers in the nuclear industry, particularly those concerned with the layout of pipework for chemical plant, experimental reactor loops, and main and auxiliary reactor coolant circuits. In brief, it is a useful work, but not without shortcomings.

M.D.W.

Books Received

Atomic Physics. (Vol. II of "Electricity, Magnetism and Atomic Physics.") By J. Yarwood. 644 pp. University Tutorial Press Ltd., Clifton House, Euston Road, London, N.W.1. (1958.) 40s.

Physics and Mathematics. (Series I of Progress in Nuclear Energy, Vol. 3.) Edited by D. J. Hughes, J. E. Sanders and J. Horowitz. 403 pp. Pergamon Press Ltd., 4-5 Fitzroy Square, London, W.1. (1959.) 105s.

Nuclear Power Plant. By E. Openshaw Taylor. 184 pp. George Newnes Ltd., Tower House, Southampton Street, London, W.C.2. (1959.) 30s.

Nuclear Reactor Physics. By R. L. Murray. 317 pp. Macmillan and Co. Ltd., St. Martin's Street, London, W.C.2. (1959.) 30s.

Automatic Welding. (A cover-to-cover translation of the Russian journal *Avtomaticheskaya Svarka*, August, 1958, issue.) Translated by J. H. Dixon. British Welding Research Association, 29 Park Crescent, London, W.1. (1959.) Annual subscription fee: £10 10s.

TRANSLATIONS

Résumés of Principal Articles

Résumé des Articles sur la Centrale d'Energie Nucléaire Latina

La centrale est en construction à Voce Verda, près de Latina, à environ 100 kms. de Rome.

L'unique groupe réacteur de la centrale est basé sur la conception Bradwell et tous les éléments principaux tels que les éléments combustibles, etc., s'appliquent directement à la Latina. Le réacteur de Latina a un rendement de 200 MW (par comparaison aux 150 MW de Bradwell) en augmentant la pression du réfrigérant de 10,47 à 13,82 kgs/cm², pression absolue; à la suite de cela il a fallu porter l'épaisseur des plaques du récipient sous pression à 111,1 mm (maximum). La prévision de tiges de contrôle supplémentaires a demandé une épaisseur de noyau de 12,72 m au lieu de 12,20 m. Pour économiser la puissance demandée par la soufflerie, les conduites de gaz ont été élargies de 1,524 à 1,676 m.

Les conditions météorologiques à Latina permettent l'installation des chaudières à l'extérieur. L'introduction de tubes à ailettes pour les surchauffeurs, une légère modification des dimensions des tubes de chaudière ordinaires en prévoyant le nécessaire en même temps pour des ailettes hélicoïdales (au lieu d'annulaires), et une conception plus compacte ont augmenté le transfert de chaleur de 33% et réduit le diamètre de chacune des 6 chaudières de 30 cm. Le rendement net total de la centrale s'est élevé de 28,2 à 28,4% à la suite de ces mesures.

Le réseau d'alimentation en Italie n'est pas du type " à grille " d'interconnexion de centrale mais du type " en étoile " alimentant des systèmes aux caractéristiques électriques variées. Ainsi, les trois générateurs de la centrale doivent fonctionner sur une gamme de puissances de 20 à 100% et à des fréquences diverses, même hors de synchronisation entre eux. Un autre facteur qui complique la disposition des commandes est le fait que les turbines et chaudières principales fonctionnent selon un circle de pression double. Dans le fonctionnement normal, les sections à haute pression des turbines sont sous contrôle de vitesse ou de régulateur alors que les sections à basse pression sont sous contrôle de pression. Les modifications de la puissance du réacteur sont mises en train en modifiant l'écoulement de réfrigérant, une opération qui s'effectue en changeant la vitesse du souffleur. Le système de commande général se compose essentiellement de deux boucles de commande: une entre la demande de vapeur et l'écoulement de réfrigérant et l'autre entre les tiges de commande et température de sortie.

Les pertes d'activité de la centrale sont strictement limitées et sous contrôle continu. La plus grande partie en est effectivement éliminée par la prévision de filtres, et d'installations de traitement de l'eau et du gaz. Les trois effluents principaux (en partie) actifs sont: l'air de refroidissement de protection, le réfrigérant (CO_2), et l'eau de mare et de lavage. L'activité gazeuse principale qui se manifeste est due à la formation d'argon-41 par l'absorption thermique des neutrons dans l'argon-40 lors du passage par le réacteur.

Zusammenfassung der Aufsätze über das Atom-Kraftwerk Latina

Das Werk ist auf einem Gelände in Voce Verda bei Latina im Bau, das ungefähr 100 km von Rom entfernt ist.

Der einzige Reaktor des Werkes ist nach dem Muster des Bradwell-Reaktors entworfen, und alle wesentlichen Teile wie Brennstoff-Elemente usw. können direkt auf Latina übertragen werden. Der Latina-Reaktor hat eine Leistung von 200 MW (Bradwell hat im Vergleich 150 MW), was durch Steigerung des Kühlmittel-Druckes von 149 auf 197 p.s.i.a. (rd. 10,5 at auf rd. 14 at) erreicht wurde. Infolge des erhöhten Druckes mussten die Platten des Hochdruckbehälters auf 4 3/8" (maximal) verstärkt werden. Die Notwendigkeit des Einbaus zusätzlicher Regelstäbe machte eine Kernbreite von 41,7' gegenüber bisher 40' erforderlich. Um die Gebläseleistung niedriger zu halten, wurden die Gasleitungen von 5' auf 5' 6" erweitert.

Die meteorologischen Verhältnisse in Latina gestatten die Einrichtung der Kessel im Freien. Die Einführung von Rippenrohren für die Ueberhitzer, eine leichte Abänderung der Dimensionen der gewöhnlichen Kesselrohre unter gleichzeitiger Anordnung schraubenförmiger Rippen (zum Unterschied von ringförmigen Rippen) und kompaktere Konstruktion haben die Wärmeübertragung um 33% gesteigert und den Durchmesser eines jeden der sechs Kessel um 1 Fuss reduziert. Die gesamte Netto-Leistung des Werks ist als das Ergebnis dieser Massnahmen von 28,2 auf 28,4% gestiegen.

Das Verteiler-Netz in Italien ist nicht auf dem System eines " Rostes," der eine Verbindung aller Werke untereinander darstellt, aufgebaut, sondern auf dem System eines " Sterns," durch den die Elektrizität in Systeme mit variierender elektrischer Charakteristik geleitet wird. Somit ist es erforderlich, dass die drei Generatoren des Werkes in einem Leistungsbereich von 20–100%, in Netzen mit variierender Frequenz, die sogar nicht miteinander synchron sind, arbeiten können. Ein weiterer Faktor, der die Anlage der Regelungseinrichtungen kompliziert, ist die Tatsache, dass die Hauptturbinen und die Kessel in einem zweifachen Druckmittel-Umlauf liegen. Im normalen Betrieb sind die Hochdruckteile der Turbinen unter Geschwindigkeits- oder unter Regler-Steuerung und die Niederdruckteile unter Druck-Steuerung. Wechsel in der Reaktor-Leistung werden durch Variierung des Kühlmittel-Stromes eingeleitet, und diese wird erreicht durch Variierung der Gebläse-Geschwindigkeit. Das Steuerungs-System ganz allgemein besteht im wesentlichen aus zwei Steuerungskreisen: Der eine Kreis steuert Dampfbedarf und Kühlmittelstrom, der andere steuert die Reaktoren-Ausflusstemperatur und die Regelungsstäbe.

Freiwerdende Radioaktivität ist eng begrenzt und unter andauernder Kontrolle. Der grösste Teil der Strahlung wird durch Filter und durch Behandlung des Wassers und der Gase in entsprechenden Anlagen unwirksam gemacht. Die drei wichtigen Abfluss-Stoffe sind: die Kühlluft des Schutzschildes, das Kühlmittel (CO_2) und das Waschwasser.

Resúmenes de los artículos sobre la Central de Fuerza Nuclear Latina

La central se está construyendo en un sitio en Voce Verde, cerca de Latina, a unos 100 km. de Roma.

La unidad única del reactor de la central está basada en el diseño de Bradwell y todos los componentes principales, tales como los elementos de combustible, etc., son directamente aplicables a Latina. El Reactor de Latina tiene un rendimiento de 200 MW (comparado con 150 MW en Bradwell) mediante el aumento de la presión del enfriante desde 149 a 197 p.s.i.a.; como resultado el espesor de las planchas del recipiente de presión tuvo que aumentarse a 4-3/8 in. (máximo). La provisión de varillas adicionales de control exigió un ancho de núcleo de 41,7 pies en lugar de 40 pies. Para economizar en potencia para el soplador, los conductos de gas han sido ensanchados desde 5 pies a 5 pies 6 pulgadas.

Las condiciones metereológicas en Latina permiten situar las calderas a la intemperie. La introducción de tubos aleteados para los supercalentadores, modificando un tanto las dimensiones de los tubos de caldera ordinarios, al mismo tiempo disponiendo para aletas helicoidales (distintas de la forma anular), y un diseño más compacto aumentaron la transferencia de calor en un 35% y redujeron el diámetro de cada una de las calderas por un pie.

La red de distribución en Italia no es del tipo de central de "rejilla" interconectada pero del tipo "estrella," alimentado dentro de sistemas de variadas características eléctricas. Así, los tres generadores de la central son exigidos a funcionar sobre una gama de potencia del 20–100% y a varias frecuencias, aunque no sincronizados uno con el otro. Otro factor que complica la disposición de los mandos es el hecho de que las turbinas y calderas operan sobre un ciclo dual de presión. En funcionamiento normal, las secciones de Alta Presión de las turbinas sobre mando de velocidad –o regulador– las secciones de Baja Presión sobre contro de presión. Los cambios en potencia de reactor son iniciados con variar el flujo del enfriante y esto se efectúa variando la velocidad del soplador. El sistema completo de control esencialmente comprende dos lazos de control: uno entre la demanda de vapor y el flujo del enfriante y el otro entre la temperatura de salida del reactor y las varillas de control.

El escape de actividad de la central está estrictamente limitado y bajo control constante. La mayor parte de dicho escape es eliminado por la provisión de filtros, y planta de tratamiento de gas y agua. Los tres mayores (parcialmente) efluentes son: El aire de enfriamiento de la pantalla, el enfriante (CO_2), y el agua de estanque y lavado. La mayor actividad gaseosa presente se debe a la formación de argón–41 por absorciones neutronicas térmicas en argón–40 durante el paso por el reactor. El nivel de radiación "tiempo-medio" en el suelo en la vecindad de la central se calcula que es 10^{-9} c/c.c., que representa un valor igual a la 1/15a. parte del máximo permisible estipulado por ICRP para menores sin ocupación.

Aspects de Physique de la Santé des Accidents de Criticalité

Trois accidents de criticalité qui ont eu lieu pendant le deuxième semestre de 1958 ont obligé le physicien en matière de santé à se pencher sur le problème de protection contre la radiation posé par de tels incidents. La généralisation de la forme d'un accident n'est pas chose facile bien qu'une étude des trois accidents en question révèle certaines caractéristiques communes. Il n'existe pas de méthode unique de détection et de localisation d'un incident, ou d'évaluation rapide des dégâts aux personnels, mais une combinaison de techniques devrait donner les renseignements nécessaires au moment où on en a besoin. Maintenant que le problème est compris de manière plus complète, les études courantes devraient permettre d'établir dans un proche avenir un choix des meilleurs systèmes de mesure.

Transfert de Chaleur de l'Elément Combustible de Hunterston

Le réacteur de Hunterston est le seul réacteur britannique incorporant des éléments combustibles de type axial polyzonal dans lequel l'écoulement du gaz le long d'ailettes longitudinales est dérangé par des agitateurs en spirale. La base des mesures de transfert de chaleur est décrite ainsi qu'une brève analyse des techniques expérimentales. Les limites imposées par le maintien du poids total de Magnox dans le noyau endéans de certaines valeurs prescrites sont expliquées et les effets du changement de divers paramètres d'éléments sont alors examinés en détail. Les résultats sont exprimés graphiquement en termes du nombre Stanton et du facteur de friction pour les diverses valeurs du nombre Reynolds.

Le Groupe Sous-critique U–H_2O du Queen Mary College

Depuis 1956 le cours d'introduction au génie nucléaire inauguré en 1951 a été élargi, mais l'accent continue à se porter sur la nucléonique appliquée, c'est-à-dire les aspects du génie de la production et de l'interaction des particules nucléaires avec la matière. En 1958, un cours supérieur fut inauguré et afin d'assurer des facilités expérimentales il fut construit un groupe à l'uranium naturel modéré à l'eau. De l'uranium légèrement enrichi pourrait aussi être employé à une date ultérieure. Outre les sources de neutrons polonium-béryllium statiques le noyau peut être activé par des neutrons produits par un groupe Cockcroft-Walton 250 kV; ce faisceau peut être impulsé pour permettre la mesure des conditions provisoires.

Le Cinquième Rapport de la Commission d'Enquête sur les Crédits

Une Commission d'Enquête de la Chambre des Communes se voit toujours, selon la pratique habituelle, confier l'étude des activités et des finances des organisations auxquelles le Trésor attribue des crédits. Au cours du premier semestre de cette année, le Groupe Industriel de l'Autorité de l'Energie Atomique (maintenant divisé en un Groupe de Production et un Groupe de Développement et Technologie) a été l'objet d'un examen très attentif. Le rapport de la Commission complimente le Groupe tant de ses réalisations techniques que de son contrôle des dépenses. Des recommandations détaillées sont faites pour les opérations de l'avenir, une des plus importantes consistant en ce que le potentiel de développement dans les entreprises industrielles soit exploité plus à fond.

Die Gesundheits-Physik und Unfälle durch Ueberschreiten des kritischen Punktes

Drei Unfälle durch Ueberschreiten des kritischen Punktes in der zweiten Hälfte von 1958 haben es nötig gemacht, dass der Gesundheits-Physiker die Probleme des Schutzes gegen schädliche Bestrahlung überprüft, die durch solche Zwischenfälle entstehen. Es ist nicht leicht allgemeine Formeln für solche Unfälle aufzustellen, wenn auch das Studium der drei erwähnten Unfälle zeigt, dass gewisse Kennzeichen allen gemeinsam sind. Es gibt keine einzige Methode der Entdeckung des Fehlers und Festlegung des Fehlerpunktes, und es gibt auch keine Möglichkeit, die Schädigung der Gesundheit der in Frage kommenden Personen rasch abzuschätzen, jedoch sollte eine Kombination der verschiedenen technischen Möglichkeiten die notwendigen Unterlagen beschaffen können.

Die Wärme-Uebertragung bei den Brennstoff-Elementen in Hunterston

Der Reaktor in Hunterston ist der einzige britische Reaktor, der mit Brennstoff-Elementen des vielzonigen achsialen Types arbeitet, bei welchen der Gasstrom entlang der Längsrippen durch spiralige Wirbelerzeuger gestört wird. Die Grundlage für die Messungen der Wärme-Uebertragung wird zusammen mit einer kurzen Analyse der bei den Experimenten angewendeten Technik beschrieben. Die Begrenzung, die dadurch bedingt ist, dass das Gesamtgewicht von Magnox im Kern innerhalb bestimmter Werte gehalten werden muss, wird erklärt, und die Wirkungen, die durch Aenderungen der verschiedenen Abmessungen eines Elementes entstehen, werden dann im einzelnen untersucht.

Die unter dem kritischen Punkt bleibende U-H_2O Apparatur des Queen Mary College

Seit 1956 ist der einführende Kursus über Atomkern-Technik, der 1951 begonnen wurde, auf eine breitere Basis gestellt worden, jedoch liegt der Schwerpunkt noch immer auf dem Gebiet der technischen Anwendung der Kernphysik, d.h. die Produktion von Atomkern-Partikeln und ihre Einwirkung auf die Materie vom Standpunkt des Ingenieurs. Ein Kursus für Studenten, die bereits ihr Examen hinter sich haben, wurde 1958 eingerichtet, und um eine Möglichkeit für Experimente zu schaffen, wurde eine Apparatur gebaut, die mit natürlichem Uran und Wasser als Brennstoff arbeitet. Ausser durch statische Polonium-Beryllium Neutronenquellen kann der Kern durch Neutronen aktiviert werden, die durch einen 250 kV Cockcroft-Walton Apparat erzeugt werden.

Fünfter Bericht des " Select Committee on Estimates " (Ausschuss zur Prüfung der Voranschläge)

Es ist normale Praxis des " Select Committee " des " House of Commons " die Tätigkeit und die Finanzen der Organisationen zu prüfen, die von Zuschüssen des Schatzamtes abhängig sind. Die Abteilung " Industrie " der " Atomic Energy Authority " (die jetzt in eine Produktions-Abteilung und eine Entwicklungs- und Konstruktions-Abteilung aufgeteilt ist) wurde einer sorgfältigen Nachprüfung der Einzelheiten unterzogen. Der Bericht des Ausschusses beglückwünscht die Abteilung sowohl zu ihren technischen Leistungen als auch zu ihrer guten Kontrolle der Ausgaben. Im einzelnen werden dann Empfehlungen für zukünftige Arbeiten gemacht, deren wichtigste sich auf die Entwicklung der Leistungsmöglichkeiten in industriellen Konzernen bezieht, die voller ausgebeutet werden sollten.

Aspectos de salud por el lado de la física de accidentes de criticalidad

Tres accidentes de criticalidad en la segunda mitad de 1958 han exigido que el físico de salud examine los problemas de protección contra la radiación que tales incidentes plantean. No es fácil generalizar la forma de un accidente, aunque un estudio de los tres arriba mencionados muestran ciertas características comunes. No existe ningún método preciso de detectar y posicionar un incidente ni de asesorar rápidamente el daño al personal, pero una combinación de técnicas deben rendir la información necesaria en el momento en que se necesite. Ahora que el problema se entiende más ampliamente, las investigaciones actuales deben permitir que en el próximo futuro se haga una selección de los mejores sistemas de medición.

Transferencia de calor de elemento de combustible en Hunterston

El reactor de Hunterston es el único reactor británico que incorpora elementos de combustible del tipo axial y polizonal, en los que el flujo de gas a lo largo de aletas longitudinales es estorbado por remolinadores espirales. La base para medidas de transferencia de calor se describe juntamente con una breve análisis de las técnicas experimentales. Las limitaciones impuestas en mantener el peso total de Magnox en el núcleo dentro de ciertos valores prescritos se explican y los efectos de cambiar diversos parámetros de elementos luego se examinan en detalle. Los resultados se expresan gráficamente en términos de número Stanton y factor de fricción para varios valores de número Reynolds.

El conjunto subcrítico U-H_2O del Colegio Queen Mary

Desde 1956 el curso preliminar de ingeniería nuclear inaugurado en 1951 ha sido ensanchado, pero todavía el énfasis estriba en la "nucleónica" aplicada, es decir, los aspectos ingenieriles de la producción y la interacción de partículas nucleares con materia. En 1958 se inició un curso para ingenieros nucleares ya recibidos y para proveer una facilidad experimental se ha construido un conjunto de uranio natural moderado por agua. En el futuro posiblemente se emplee uranio un tanto enriquecido. Además de las fuentes neutrónicas estáticas de polonio-berilio, el núcleo puede ser activado por neutrones generados por un equipo Cockcroft-Walton de 250 kV; este destello puede ser pulsado para permitir mediciones de condiciones transitorias. El laboratorio se describe en detalle y los métodos de medición de flujo, juntamente con trazados de estado estables típicos son ilustrados.

Quinto Informe De Comité Selecto de Presupuestos

Es la práctica regular de un Comité Selecto de la Cámara de Comunes investigar las actividades y las finanzas de las Organizaciones que dependen de contribuciones del Tesoro. Durante el primer semestre de este año, el Grupo Industrial de la Autoridad de Energía Atómica (dividido ahora entre el Grupo de Producción y el Grupo de Fomento e Ingeniería) fué objeto de un cuidadoso escrutinio. El informe del Comité felicita al Grupo tanto por sus labores técnicas como por su control de gastos. Se hacen recomendaciones detalladas para operación subsecuente, siendo una de las más importantes que la potencial de desenvolvimiento en entidades industriales deberá ser explotada más ampliamente.

CYLINDRICAL GLOVE BOX with Rotating Table

By K. W. BAGNALL, D. S. ROBERTSON
(*King's College, Newcastle upon Tyne*)
and
S. J. G. PARKES, P. S. ROBINSON, M. A. A. STEWART
(*Boucher and Co., Ltd.*)

FROM experience gained in work with very high levels of α-activity and, in particular, with the shorter-lived α-emitters of high specific activity, such as Po^{210}, it became clear that the conventional rectangular section glove-boxes were by no means ideal for this type of work. In the Mk 1 and Mk 2 glove-boxes used at AERE, the maximum floor area inside the box which is available to an operator at any one pair of glove ports is, at best, only about 6 sq ft. In the Mk 2 box, the total floor area is approximately 12.5 sq ft and four sets of glove ports are provided so that the whole of this area may be utilized; the working area available at any one pair of glove ports is only a little more than 3 sq ft. This is often inconvenient where a sequence of complicated chemical operations has to be carried out, for example, the purification of starting material, followed by the preparation and analysis of a new chemical compound.

It is found also, in general, undesirable to have more than one operator working in any given glove-box, for confusion of apparatus or source material may occur. The basic requirement, therefore, is for all the floor space to be made available to one operator, at one pair of glove ports.

This would be met by a cylindrical glove-box, with one pair of glove ports giving access to a rotating table, the radius of which would be the length of reach of the average man, 27 in. and providing a possible floor area available to one operator of approximately 15¾ sq ft. A single instance of a glove-box containing a turntable has been previously recorded*; in this case, an electrically operated turntable, carrying heavy engineering equipment, was housed in a very large rectangular box. There does not, however, appear to be any record of a laboratory glove-box of this type.

Rough sketches of a proposed box were made at AERE and the final design was developed in collaboration with Boucher and Co., Ltd., Kidderminster who also undertook the construction. The final product is shown above.

The Complete Unit

The unit consists of a cylindrical box 4 ft 6 in. in diameter, with 3-ft high walls of 16 gauge mild steel, held on to a tubular steel stand by six simple clips. The frame is set on castors and screw jacks for rapid and accurate positioning. The roof of the cylinder is domed (convex outwards) for additional strength and is welded to the wall. The plane viewing window, carrying two glove ports, is fixed along a tangent to the cylinder, and the base of the cylinder wall is flanged and is bolted against a neoprene gasket to a ¼ in.-thick circular mild steel base. There is no necessity for the base to be detachable and in future models it would be sufficient to weld the cylinder wall to the base plate. Connection to other boxes is made by means of a square section trunking attached to this base plate. The overall height of the unit is 6 ft. 10¼ in.

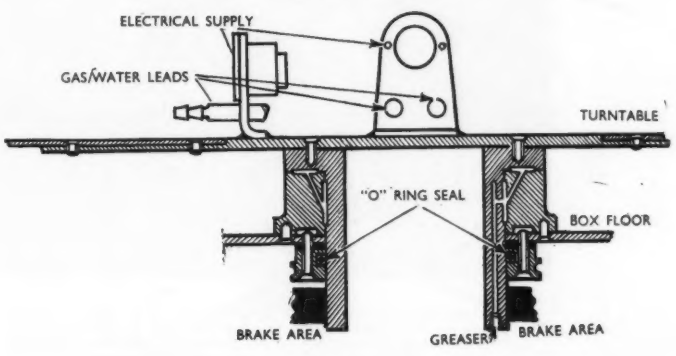
Fig. 1.—Double window system; viewing from right.

An explosion port consisting of a 6-in. glove port on which rests a 13 oz rubber beach ball (7½ in. diameter) is fitted at the centre of the domed roof. It is contained inside a pvc sleeve which is connected to the laboratory extract system. When the box is pressurized above approximately 1 in. water gauge, the ball lifts, releasing the pressure. The lead from the CO_2-type fire extinguisher (Pyrene CD5), which is clipped to the wall adjacent to the viewing window, enters the box close to the explosion port. Provision for four permanent reagent leads into the box is made by drilling the necessary holes in the flat roof of the viewing window segments. These leads pass through rubber grommets fitted to the entry holes.

The glove-box extract filter is inside the glove-box and is contained in a close-fitting box welded to the wall; the extract (a venturi air-ejector) is screwed into the outside of the box. An 8-in. posting port is fitted to the wall on the side opposite to the filter.

A double window system (Fig. 1) has been adopted in which the inner window, carrying the glove-ports, is held against a neoprene gasket on an extension to the wall of the box, whilst the outer

Fig. 2.—The turntable bearing assembly showing the lubrication system and method of sealing.



* Dolphin, J. R. V., in "Glove Boxes and Shielded Cells." Butterworths Scientific Publications, Ltd., London, 1958, p. 255.

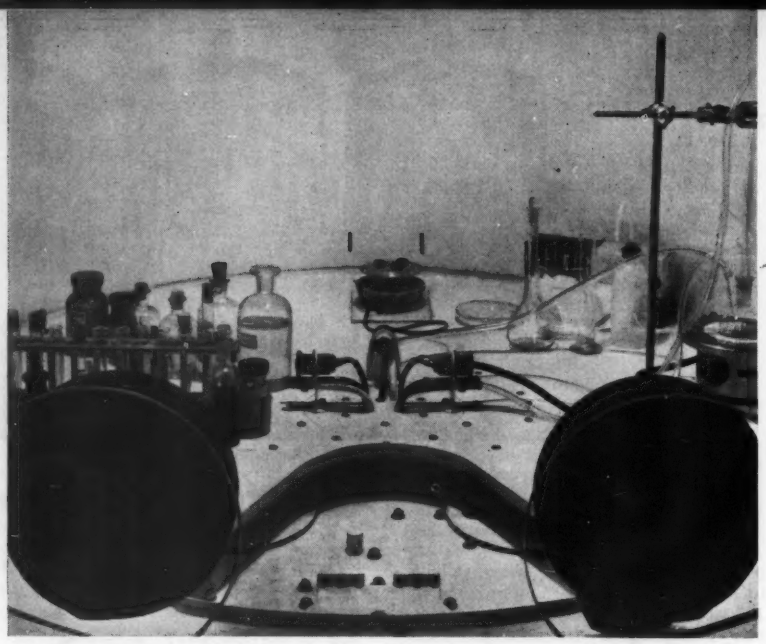


Fig. 3.—View of box area with characteristic apparatus on the turntable. Kidney shape is to facilitate transfer of material and equipment.

window is bolted to a wide flange, welded to this window extension. The flange is arranged so that the box can be attached to the frog-suit area at AERE for decontamination, repair, etc.

The space between the two windows is maintained under slightly reduced pressure by applying suction to the pipe at the top and the exhaust from this is fed into the building extract.

The Turntable

The turntable, of 10 gauge mild steel, is mounted on a flanged central plate and is supported on six castors spaced evenly round the periphery. These castors run on a circular Tufnol strip placed on the floor of the box shell; they are ball-type units and may be unscrewed from the turntable for servicing inside the box.

The central plate, which also bears the service leads, rotates on a 6 in. diameter aluminium bronze sleeve bearing, which is provided with grease channels in its vertical and horizontal surfaces, the grease being supplied by a screw-up greaser fitted to the bearing surface projecting below the box shell. The bearing is sealed against leakage of radioactive dust by an O-ring seal below the floor of the box, in such a position that the seal can be replaced without risk of an escape of radioactivity (Fig. 2). The turntable is so arranged that its level is 41 in. above the laboratory floor.

Since the bearing will ultimately require servicing, the turntable is made divisible along a diameter, the two halves being connected by screwing them to metal T-ribs. A sector (Fig. 3) is cut out of the turntable to permit access to the centrifuge port, the connecting trunking or the trash disposal port. All of these are mounted on the floor of the box shell and are covered by hinged lids, that to the connecting trunking being held against a gasket by means of a retaining clip in order to provide an air seal. Allowing for the cut-out sector, the total working area is approximately 14 sq ft.

A simple stop is provided inside the box so that the turntable can be turned through one complete revolution only, avoiding undue torsion of the service leads. When the turntable is at rest, a brake is permanently applied to an extension of the sleeve bearing which projects through the floor of the box. This is released by applying pressure to a pedal, mounted on the lower part of the box frame.

Trunking

When a set of boxes is to be used for work with the same radioactive isotope, it is convenient to be able to transfer material or small items of equipment from one box to another and to transfer samples from any of the boxes to a box containing the counting equipment. Each of the glove-boxes is therefore fitted with a 5-ft length of 16-gauge square section (6 in.) sheet steel trunking, connected to the floor of the box shell by a 6-in. length of tubing (6 in. diameter). A small Perspex window is provided on the face of the trunking at the junction with this tubing.

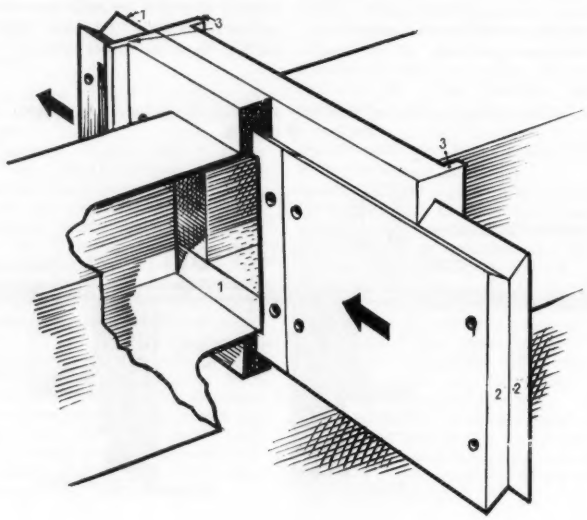
The trunking ends are flanged and are provided with grooves, with ground faces (Fig. 4), into which slide well-greased connecting or sealing plates. In normal use, bolts pass through the connecting plates and the flanges of the trunking end plates; this minimizes the strain on the locking grooves.

Transport of material from one box to another is effected by means of a small electrically propelled trolley running in this trunking. This trolley is driven by an electric motor (1/40 h.p., 3 ph, 400 V, 50 c/sec) mounted on one end, the power supply being fed in by a trailing cable which is kept taut by a Wayne self-winding reel; this is housed in the glove-box attached to the end of the trunking. The trolley is mounted on rubber-tyred wheels and is aligned in the trunking by two pairs of similar wheels on the sides of the trolley.

Finish

The inside of the box, including the turntable, is painted with white "Epilac" epoxy resin paint; externally the box is finished with "Dulux" paint, each box being painted a different colour for easy identification in the event of an accident. Although the "Epilac" finish has a relatively high resistance to corrosive vapours, it is probable that a box shell moulded from fibre-glass would be better for work under extreme conditions.

Fig. 4.—Method of disconnecting two boxes. A trunking locking plate (1) is displaced by a pair of blanking plates of the same size (2). Secondary flanges are formed on the trunk end flanges (3) to engage receivers (not shown) for the displaced members.



Processes and Equipment

For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

Nuclear Test Rig

A 500,000-dollar test rig for reactor components has been completed by Humphreys and Glasgow (Canada), at Toronto, for the Nuclear Power Plant Division of Atomic Energy of Canada. The rig consists of two test loops, each basically a water-circulating system capable of being operated at the high temperatures and pressures encountered in nuclear reactors. They will be used primarily for testing equipment and components having a direct bearing on the CANDU reactor programme.

The rig is installed at the A.W. Manby Service Centre at Toronto of the Ontario Hydro-Electric Power Commission. It occupies a ground-floor area of about 5,000 sq ft. An existing mezzanine floor at 20 ft elevation and a new platform at 8 ft provide access to the rig. The ends of the loop manifolds on the rig stretch almost 100 ft, while the centre lines of the manifolds run parallel to one another, and for each loop are 28 ft apart.

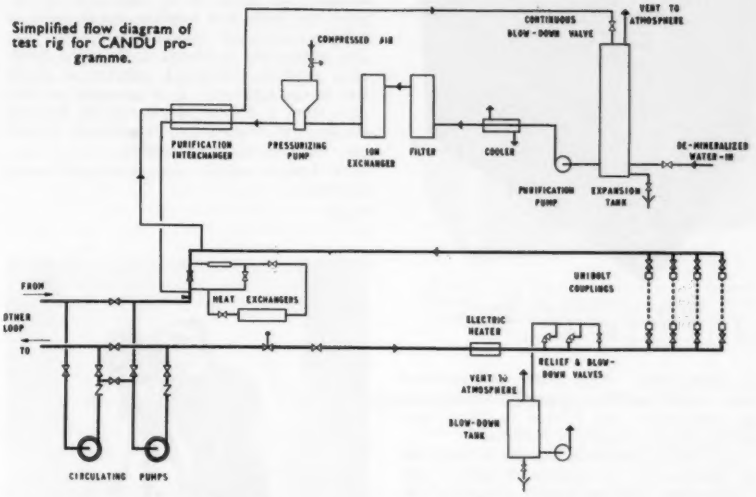
Two basic types of experiments will be conducted on the rig.

In one, heat will be produced at a constant rate in an experimental test section to study heat transfer characteristics of the heating element. The temperature of the circulating water will be regulated by dumping heat in excess of that generated and then controlled by an electric heater, external to the test section.

The second type of experiment involves no heat input from the test section and the temperature of the water will again be controlled by over-cooling the rig and operating the electric heater on automatic temperature control. The rig was commissioned and in use only eight months after commencement of design.

(Humphreys and Glasgow, Ltd., London.)

1218



Simplified flow diagram of test rig for CANDU programme.

Pressure-moulded Bricks

Lead bricks for shielding purposes produced by pressure moulding are now being marketed by British Lead Mills. Pressure moulding ensures a greater density and freedom from porosity. The bricks are produced in 2 in. and 4 in. thicknesses in the following forms: standard, corner, top and bottom, half and quarter. By virtue of the Vee interlocking feature bricks can be built up into a complete surround, the ultimate thickness being from 2-in. upwards in multiples of 2 in.

(British Lead Mills, Ltd., Byron House, 7/9 St. James's St., London, S.W.1.)

1219

Visual Flow Indicator

An inexpensive and more compact version of the Telicator liquid flow indicator has been added to the range available from Sir W. H. Bailey and Co., the sole agents and distributors for the manufacturers, Dukes and Briggs Engineering.

The unit is designed for insertion in pipelines, the ends being threaded $\frac{1}{4}$ in., $\frac{3}{8}$ in. or $\frac{1}{2}$ in. B.S.P.T., and for use with liquids having temperatures of up to 80°C. It can be used with high or low pressure systems and with liquids of almost any viscosity. One of the main advantages over previous models is that it can be completely dismantled for cleaning without breaking the pipe connections. The new unit—known as K-type—is only $2\frac{3}{4}$ in. long and contains a Perspex cylinder housing a rotor which is located by pivots and sprung bearings, so that the flow of a liquid is readily revealed by the revolving rotor. The method of pivoting the rotor is claimed to reduce friction to a minimum, so that the rate of flow of a liquid is hardly affected.

(Sir W. H. Bailey and Co., Ltd., Albion Works, Patricroft, Manchester.)

1220

The control desk of one of the two Savage and Parsons power-operated manipulators which were installed recently at Windscale by the United Kingdom Atomic Energy Authority for the continuous remote-handling of spent fuel elements from the Calder Hall reactors.

Precision Inspection Unit

Precision machined workpieces call for vigorous inspection: a new unit introduced by Ferranti makes use of the company's ingenious co-ordinate inspection system with an accuracy of 0.001 in. Quite apart from the inspection of precision components forming part of charge/discharge machines or manipulators, the new Ferranti unit could also be used to check dimensions of irradiated specimens.

The operator, has under his control an inspection probe with interchangeable tips suitably shaped to locate at any point on a

The Ferranti co-ordinate inspection machine provides a rapid means of inspecting workpieces.

machined part. This probe is supported from a rigid cantilever beam projecting over the work-table, and is free to move over the length and breadth of the table.

Low friction bearings provide a minimum of resistance to movements in both x and y directions, the maximum travel of the probe in the x direction being 24 in. and in the y direction 15 in. Travel in the vertical direction, which at the moment is not used for measurement, is 10 in. and the probe is spring-loaded towards the upper limit of travel.

Electro-optical sensing units are fitted to the x and y axes of the machine. Motion along either axis, causes the Moiré fringe pattern generated by the associated diffraction gratings to traverse photocells, where changes in light intensity are converted into their electrical counterpart. Transistor bi-directional decade counters (one for each axis) record the cyclic variation.

As information of measurement is displayed continuously on two five-figure electronic counter banks, the position of the probe at any point in its x and y travel can be read-off directly to an accuracy of 0.00-1 in. or 0.02 mm.

(Ferranti, Ltd., Hollinwood, Manchester, Lancs.)

1221

New Infra-red Bolometer

A new bolometer, operating on the principle of a change of resistance being produced in a strip of gold leaf when exposed to infra-red rays, has been developed by H. Tinsley and Co. Uses of the bolometer include detection of hot spots in machinery and equipment which it is not possible or convenient to touch or approach near enough to use other types of instruments. It can, for example, detect bad joints in high voltage cables whilst the high voltage is ON, this requiring no more than focusing the joint on the bolometer window. It also applies to such things as equipment emitting a high level of radioactivity, or where local atmospheric conditions create a potential danger. It can be used for taking temperatures on rotating parts of machinery.

The bolometer operates by the change in resistance produced in a strip of gold leaf when infra-red rays fall upon it. The gold leaf strip—coated with lamp black so that it will absorb and not reflect the infra-red rays that fall upon it—is about one millimetre in width held across three supports so that it makes two equal arms making electrical contact at the points of support. These form the arms of a Wheatstone Bridge network.

The assembly is mounted in a small draught-free box. Over one arm of the gold leaf there is a window, transparent to infra-red rays of wavelength up to 10μ. The whole unit is placed at the focal point of a concave cylindrical reflector of about five inches aperture. It is arranged so that rays from a distant object can be focused on the arm of gold leaf immediately behind the window of the assembly.

(H. Tinsley and Co., Ltd., South Norwood, London.)

1222

The new infra-red bolometer developed by H. Tinsley and Co.

Glove Box Hoist

A special remotely controlled glove box hoist has been designed and is being produced by the Hawker Siddeley Nuclear Power Company. It has a lifting capacity in its present form of 3 cwt and such loads can be lifted 5 ft at speeds ranging from 0 to 12 ft per minute. The unit height from the top of the channel rails supporting it to the centre line of the hook is only 10½ in., considerably less than that of normal hoists for the same duty.

When gantry mounted, the hoist hook can drop to within 7 in. of the ends of a glove box or similar housing and to within 10 in. of its sides. The hoist can be supplied individually or in glove boxes made by Hawker Siddeley Nuclear Power Company.

(Hawker Siddeley Nuclear Power Co., Ltd., Sutton Lane, Langley, nr. Slough, Bucks.)

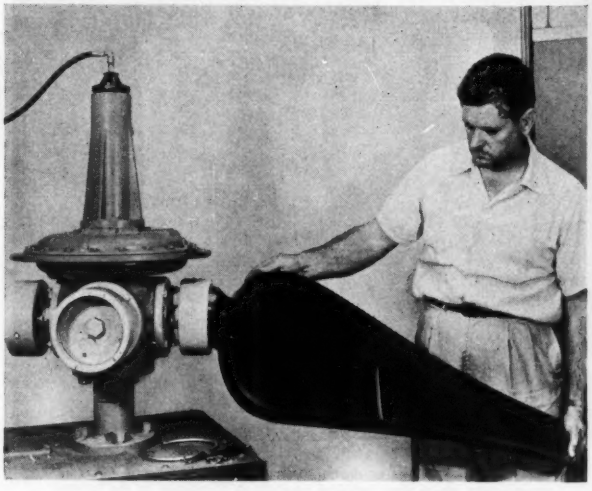
1223

Hollow Plastic Fans

Marston Excelsior, a subsidiary of ICI, have acquired from the Hudson Engineering Corporation of Houston, Texas, the sole right to manufacture Hudson hollow plastic industrial fans, in the United Kingdom. The fans will be sold under the trade name Marex.

Initially, the standard range will consist of four-bladed fans ranging from 6 to 14 ft in diameter in increments of 2 ft in diameter. A set of hollow plastic blades may be fitted to two types of hub, either the auto-variable hub, which by means of a pneumatically activated diaphragm alters the angle of pitch while the fan is in motion, or the adjustable pitch hub, which requires that the fan be stopped while a simple manual alteration of pitch is carried out. On both hubs the angle of pitch may be varied between −15° and +30°.

The advantages of these fans over conventional wooden and metal types lie in the materials, method of construction and the aerofoil shape. Blades are made of woven glass cloth and pigmented epoxy resin, laminated as a one-piece moulding. These materials make a self-coloured blade, which is corrosion- and heat-resistant; the method of construction gives blades of smooth surface, high strength and low



Fitting a blade on the Marex industrial fan (Marston Excelsior).

weight. They will not shatter or fragment and being hollow, are extremely light; a set of blades for a 10-ft. diameter fan weighs 58 lb. Following extensive wind tunnel tests, the blade contour, a true aerofoil section, has been determined to give optimum performance characteristics. Fan blades of the same size are readily interchangeable as all blades are balanced at the works to a standard value.

Installations in America and in this country are giving entirely satisfactory service moving hot dry air through heat exchangers in desert areas, moving hot moist air from water cooling towers, moving corrosive laden air from chemical process vats, and in large volume ventilation systems.

(Marston Excelsior, Ltd., Wolverhampton, Staffs.)

1224

The Nanoscope

This auxiliary unit connected with an ordinary laboratory oscilloscope permits the observation of very fast repetitive waveforms of the order of a few nanoseconds (10^{-9} second) duration. It has been developed by the Atomic Energy Research Establishment, Harwell, primarily for use with scintillation counters. The device operates by sampling the fast waveform with very narrow pulses at a number of points. This results in the production of a series of pulses, stretched to render them visible on a normal oscilloscope of restricted bandwidth, which are proportional in amplitude to the corresponding ordinates of the sampled waveform. These ordinate pulses are brightened at their peaks, thus tracing the fast waveform as a series of dots on the oscilloscope.

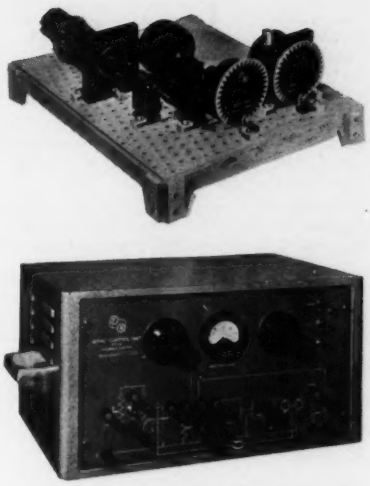
Circuits within the Nanoscope unit provide for the sampling of the waveform at progressively later points: they ensure that once a sampling has been made it is not possible for the sampling circuits to be triggered into action again until the first sample has been displayed on the screen.

In order that the sampled pulses may be centred on the screen, which shows only a very small period of time in the interval between pulses, means are provided to delay the sampling pulse until the timebase sweeps have started and have reached the appropriate point for the display. Coarse and fine delay adjustments are provided for this purpose. The latter is a helical potentiometer with 1,000 divisions, the whole of its range being equal in delay to twice the time-base sweep. Since this can be set to as low as 50 nanoseconds, it follows that each division of the fine delay potentiometer corresponds with 0.1 nanosecond. The instrument is therefore capable of measuring very short intervals in time. The intrinsic rise time of the device is somewhat in excess of 2 ns.

The equipment is provided with a probe which, with range switches on the main unit, gives four settings for input voltages from 0.5 V to 30 V. An internal square-wave generator enables the amplitude of the waveform being examined to be checked to within 5%. A feature of the equipment is the very low noise level which has been achieved.

(Lion Electronic Developments, Ltd., Hanworth Trading Estate, Feltham, Middx.)

1225



To teach the basic theory of servo systems Feedback, Ltd. of Crowborough, Sussex, have developed this interesting instructional system, type ESIA.

1226

Television Lighting for Hunterston Charge Machine

The problem of providing lighting for television cameras on a nuclear-reactor charge machine has recently been investigated experimentally by the illumination department of the G.E.C. Research Laboratories. At Hunterston the charge machine, situated beneath the reactor, will handle a complete stack of 10 fuel elements in one operation, each different operation being carried out in a series of automatically sequenced groups. The movements will be monitored by instruments on the remote control desk, but it is also desirable for the operator to be able to check the functioning of certain parts visually, particularly in an emergency. This will be done by means of closed-circuit television, monitors being built into the control desk.

The quality of a television picture is dependent on a number of factors, but in particular on the intensity and direction of the object lighting with respect to the camera and on the amounts of light reflected by different parts of the object. Because of the complexity of the mechanical system and the large number of different operations that had to be considered, the positions of the cameras, and the positions and intensities of the lamps, could not be deduced reliably just by calculation from the drawings. But they had to be determined before fabrication of the pressure vessel for the machine. A full-scale wooden model of the operating mechanisms concerned was built at Erith and re-erected at Wembley for experimental tests. The model—built on its side, for convenience in operation, so that the principal movements were horizontal rather than vertical—represented the top part of the charge machine, occupying a roughly cubic space of 12-ft side. Operations such as removing and stowing the standpipe door and concrete shield plug, locating the charge tube, inserting and withdrawing fuel elements, could all be simulated by manual operation of parts of the model.

(Left) Part of the Hunterston charge-machine model with a test card being used to check picture quality.

In the actual machine at Hunterston illumination will be by 125-W high-pressure mercury-vapour lamps, mounted on the outside of the pressure vessel and shining through glass windows. This type of lamp was chosen because of its high efficiency and high actinic value in relation to the camera tubes used. For the purpose of the experiments a frame representing the pressure-vessel wall was erected at the correct distance from the model, and the lamps, behind simulated sight glasses, mounted on the frame. A comprehensive series of tests was then carried out to determine the most suitable positions of lamps and cameras.

An important conclusion from the experiments has been that lighting positions are quite critical if best results are to be obtained. Certain of the mechanisms are masked by others and in order to see these it is necessary to attach special pointers to them to show their movement. During the course of the tests it was found that the two-dimensional presentation of an essentially three-dimensional object sometimes produced the optical illusion of " inversion," that is, a nearer edge sometimes appeared to be farther away. The solution to this particular difficulty has been obtained by painting contrasting stripes on some parts of the mechanism to accentuate their shapes and emphasize their true perspective.

The use of appropriate paints can improve picture quality, but special care must be taken in their selection. The inside of the machine effectively forms part of the coolant-gas circuit, when it is connected to the reactor, and there are severe restrictions on the types of material that may be introduced into this circuit. In addition, the radiation intensity due to spent fuel elements withdrawn into the machine will be very high, and it is necessary for the paint not to be affected by this.

With the arrangement finally chosen it was found possible to obtain good pictures with an illumination of 10-40 lumens/sq. ft over the important sections.

(General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.)

1227

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 806,001. Manufacture of uranium. E. W. Colbeck and U.K. Atomic Energy Authority.

Molten uranium is subjected to a high vacuum (10^{-4} to 10^{-5} mm Hg) at 1,500° to 1,800°C to obtain high-purity metal.

B.P. 806,031. Production of uranium. T. Wathen and U.K. Atomic Energy Authority.

Massive uranium metal is produced by the reaction of an anhydrous uranium tetrahalide with an alkaline earth metal (including magnesium) in an atmosphere containing free oxygen at superatmospheric pressure (10 to 40 atm). A suitable reaction vessel is described in B.P. 805,191.

B.P. 806,138. Closure for pressure vessels. Foster Wheeler Ltd. (U.S.A.).

Refers to vessels such as the high pressure head of a heat exchanger. A flexible diaphragm in the form of a very thin flat metal sheet is pressed by a pressure plate through a diaphragm ring onto a peripheral tongue to form a fluid-tight joint. The pressure plate is secured to the vessel wall independently of the means for securing the ring. Shear blocks transmit the thrust on the pressure plate to the vessel walls.

B.P. 806,306. Neutron detectors. General Electric Co. (U.S.A.).

The detector unit consists of a samarium oxide target in the form of a disc placed across the path of a neutron beam passing through two annular scintillation counters with an approximate inside diameter of 4 in., assembled in axial alignment. The scintillator should be toluene-terphenyl on account of its fast response time (about 10^{-9} seconds). Each of these scintillation counters is fitted with a set of photomultipliers. The signals produced by each set of photomultipliers are amplified and fed into a coincidence circuit. Only if the signals received from both sets of photomultipliers are simultaneous, will the output counting circuit be triggered. This eliminates recording of spurious signals occasioned by neutrons scattered from the target into one of the scintillation counters only, as distinct from the case of the target capturing neutrons when the resultant gamma rays or photons produce scintillations which are "seen" by both sets of photomultipliers.

B.P. 806,409. Control system for nuclear reactors. J. W. Bayles, J. R. Dean and A. Reyrolle and Co. Ltd.

An arrangement is described whereby the control rod (or group of rods) is suspended by a flexible cable wound round a windlass drum coupled via a reduction gear to a motor. The opposite end of the motor shaft carries a second gear box which, in turn, communicates with a rotating-disc electromagnetic induction brake. The motor controls the movement of the rods in a known manner under normal operational conditions, but no clutch is provided (as is included in conventional mechanisms of this kind) to facilitate a rapid drop of the rod in an emergency shut down. Instead, by suitable choice of dimensions for the components (e.g., a low gear-ratio), the inertia of the driving system is kept at sufficiently small a value for the rod to drop at an acceptable speed, say, 20 ft in 5 seconds, driving the de-energised motor in reverse through the gearing. To assist in braking the fall of the rod, a variable-ratio gear box should be used between brake and motor.

B.P. 806,430. Fuel element for nuclear fission reactors. Deutsche Gold-und Silber-Scheideanstalt vorm. Roessler (Germany).

Made as a porous moulded body the pores representing at least 5% of the total volume. Thus gaseous fission products, such as xenon, can escape through the pores by a diffusion mechanism phenomena. The fuel elements should be exposed directly to the reactor coolant (CO_2; helium) and should not be canned, so that the injurious gases are constantly discharged by the heat transfer medium passing over the elements.

B.P. 806,460. Heterogeneous nuclear reactors. R. V. Moore and U.K. Atomic Energy Authority.

The conventional design of filters, employed in heterogeneous reactors for the trapping of solid fuel particles which may have passed into the coolant stream as the result of a burst slug, involves the provision of undesirable and bulky constructional features such as special filter chambers. Instead, it is proposed to use a tubular-shaped filter of dimensions, suitable for insertion into the outlet end of the fuel element channel. Essentially, the new filter consists of an outer and inner cylinder, made from perforated material, and the actual filter element in the form of a closely wound helix of nickel wire (of trapezoidal section) positioned between them. Normally, the bottom of the filter assembly is closed by a ball valve but, should the filter element be blocked, the coolant can pass through the interior of the assembly. A typical cross-sectional area of such filters is 150 sq. ft.

B.P. 806,757. Nuclear Reactors. J. Shaw Hollings and Rolls-Royce Ltd.

The proposed reactor design consists essentially of a pressure vessel, positioned vertically, fuel elements resting on, and fixed to, a supporting plate at the bottom of the vessel and a neutron-absorbing grid with bores of suitable dimension to fit, and be lowered, over the fuel elements to cover any desired length of the latter. Assuming that the fuel elements are of hexagonal cross-section, the absorber grid is of honeycomb form. The grid may be divided into several sections (radially), each section being displaced by a separate drive. Movement is effected by ram action, the fluid employed for the action being the same as the coolant used in the reactor, i.e., water, liquid metal or gas. The pressure of the fluid supplied for operation of the ram is higher than that prevailing in the pressure vessel. In order to facilitate proper emergency shutdown speeds the fluid supply to the ram is shut off, the fluid present in the mechanism is drained and, as a result of the pressure exerted by the coolant entering the ram mechanism through an appropriate valve, the absorber grid drops down, covering the full length of the fuel elements.

B.P. 806,975. Distillation columns. H. K. Rae, A. R. Bancroft and U.K. Atomic Energy Authority.

Equipment for the distillation of heavy water operates on the principle of the wetted-wall, i.e., the liquid is passed over the column surface in the form of a film and the vapours penetrate into the centre of the column, rising along its axis. Such columns may be 50 ft high or more and considerable difficulties are encountered in aiming at a uniformly wetted surface of the column. To improve operational conditions it is proposed to introduce a packing consisting of a series of units, each made up from a number of metal sheets, parallel to and spaced at equal distance from each other, the units being stacked in such a manner that the sheets of one unit are inclined at 45° to those of the adjoining unit.

B.P. 806,984. Charge tube sealing plugs for nuclear reactors. D. M. Watts, D. B. Radford and English Electric Co. Ltd.

Details are given of a novel design of plugs sealing charge tubes of the kind which pass through the biological shield and pressure chamber wall of a heterogeneous reactor. The plug which is fitted with rubber rings of the O-ring type carries a number of latch members spaced angularly round the top of the plug each connected to a sleeve mounted slidably over a spindle in the axis of the plug. By moving the sleeve in the downward direction, the latch members are caused to enter into an annular recess in the bore of the charge tube and by appropriate operation of a transverse key which forms part of the spindle the sleeve and thereby the latch members are locked in that position. In order to withdraw the plug, a pressure chamber and valve are connected to the outer end of the charge tube and after equalizing the pressure on both sides of the plug a special tool is lowered into the tube which engages the transverse key and unlocking of the plug can be effected.

B.P. 806,985. Cooling system for heterogeneous nuclear reactors. J. H. Bowen and U.K. Atomic Energy Authority.

An improved design of a cooling system of the "central-entry" type suitable for use with gas-cooled graphite-moderated reactors or, alternatively, gas-cooled heavy-water moderated reactors is described. The essential feature is a barrier tube inserted in the fuel channel between the fuel elements and the wall of the channel, thus creating an inner and an outer path for the coolant sweeping the channel. The barrier tube has a hole half way up the channel facilitating communication between the inner and the outer path. In operation the coolant gas is fed to the outer (annular) path of the fuel channel from each end. The gas sweeping up (or down) the outer path penetrates through the aforementioned hole into the centre of the barrier tube and returns to the respective outlet along the inner path. Two separate gas coolant circuits are employed complete with heat exchangers, each serving one end of the channels. The new design aims at reducing the temperature rise in the coolant fluid while resident in the reactor resulting in greater uniformity of the temperature distribution in the core. At the same time it permits operational coolant temperatures lower than are feasible in known reactors.